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ORIGINAL PAPER

The marine splash midge *Telmatogon japonicus* (Diptera; Chironomidae)—extreme and alien?

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Abstract We found all developmental stages of the midge *Telmatogeton japonicus* (Chironomidae) on offshore windmills near the major Swedish seaport Kalmar in the southern Baltic Sea. This might be the first record of an insect species really inhabiting the offshore areas of the Baltic Sea. A thorough analysis of previous findings of the species, its history in Europe and its ecology indicates that *T. japonicus* quite likely is an alien species in Europe introduced from the Pacific Ocean. Shipping is probably the vector, as all records in the Baltic Sea and several from the Eastern Atlantic Sea are near major seaports. Our analysis further suggests that *T. japonicus* might be both advantageous and disadvantageous to native species in the Baltic Sea. *T. japonicus* should be kept under observation within monitoring programmes as it might expand its distribution as a result of the construction of new windmills in the Baltic Sea and elsewhere in European marine and brackish water habitats.

Keywords Baltic Sea · Invasive species · Marine insect · Offshore windmills · *Telmatogeton japonicus*

Introduction

Brackish water sets the limit of distribution both for marine and freshwater species. Species confined exclusively to brackish conditions seem to be few (Remane and Schlieper 1971; Barnes 1989).

Even if far from the species numbers found in truly freshwater or truly marine habitats, shore areas of brackish habitats may contain a relatively large number of animal and plant species. This is also true for the Baltic Sea in northern Europe. Non-biting midges (Chironomidae, Diptera) can be taken as an illustrative example. More than 160 species of the midge family are known from the northern Baltic Sea coastal or archipelago areas (Paasivirta 2000). Most of them are abundant in freshwater and some in marine conditions.

In contrast, offshore brackish areas are generally species poor not only regarding insects (Smith 2001). No insect species seem to have been reported to inhabit the open Baltic Sea so far.

The number of insect species is also very limited in offshore marine areas (Ward 1992). Among true marine insect species a few species of the chironomid genus *Pontomyia* are known (Buxton 1926; Bretschko 1982). *Telmatogeton japonicus*, another marine chironomid,

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might also been seen as a genuine marine species as it has recently been found on offshore windmills in the European North Atlantic Ocean (Elsam Engineering A/S 2005) and on offshore buoys (Kerckhof et al. 2007).

T. japonicus needs special attention as it is suspected to be an alien species introduced by shipping in the eastern Atlantic Ocean (Kerckhof et al. 2007) and the southern Baltic Sea (Szadziewski 1978; Solarz 2007). It is also known from marine areas in the Pacific Ocean (Japan, Hawaii and Australia), the North American coast of the western Atlantic and the islands of the Azores, Madeira, Ireland and Iceland (De Jong et al. 2007).

The many recent mainly offshore records of *T. japonicus* in Europe, and often in large numbers, call for an assessment of its potential to extend its spatial distribution and possible undesirable ecological impact.

Material and methods

Scientific as well as other literature (e.g. monitoring reports) were employed to be able to assess the potential ecological effects of *Telmatogeton japonicus* in the Baltic Sea. Collected field material of *T. japonicus* was also used.

While working within the project DOWNWInD (*D*istant *O*ffshore *W*indfarms with *N*o *V*isual *I*mpact *in* *D*eepwater) surveying the fish community around the seven offshore windmills at the wind farm Utgrunden 1 in the southern Kalmar Strait of the Baltic Sea (Fig. 1), observations were made by M. H. Andersson in August 2007 of a frequent occurrence of a dark midge on the windmill foundations in the splash zone (Fig. 2). When returning in October the same year, three samples of the adult midge were recovered by a SCUBA diver swimming in the surface water using a small landing net. Several larvae and pupae of the midge were sampled from the splash zone (the water surface and 50 cm upwards) by the collector standing on a ladder connected to the wind turbine foundation, and samples were taken using a knife and tweezers. All organisms were stored in 70% alcohol for transportation and analysis. At the wind farm Yttre Stengrund 30 km south of Utgrunden (cf. Fig. 1), visual observations of larvae and flying adults of

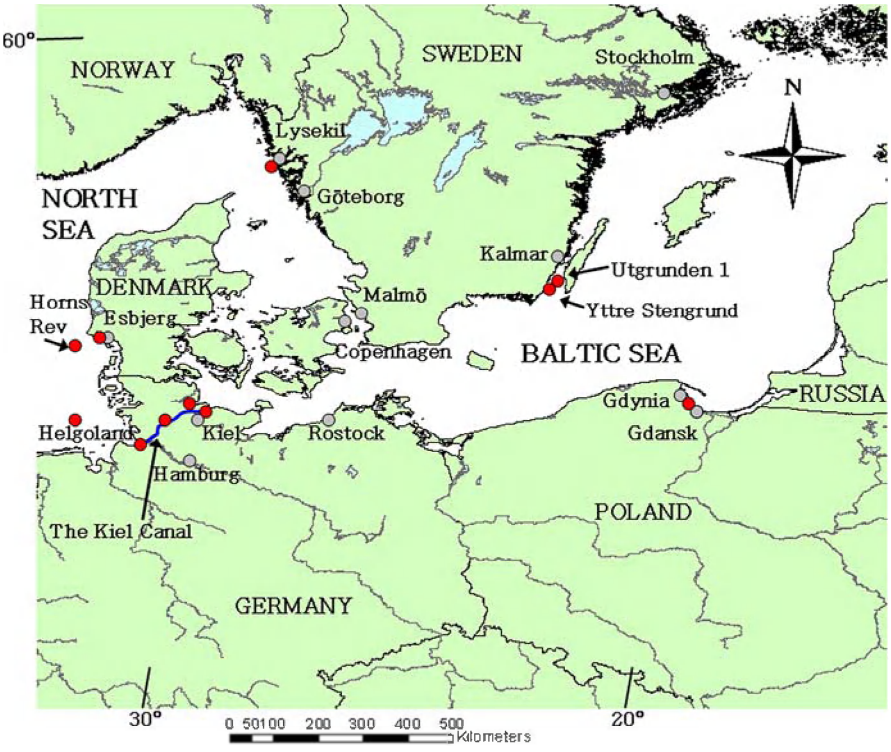

Fig. 1 Findings (dark/red circles) of *Telmatogeton japonicus* in the southern Baltic Sea and the adjacent part of the North Sea (Atlantic Ocean). The present study was done at Utgrunden 1. Important ports for shipping near the findings are indicated as light grey circles

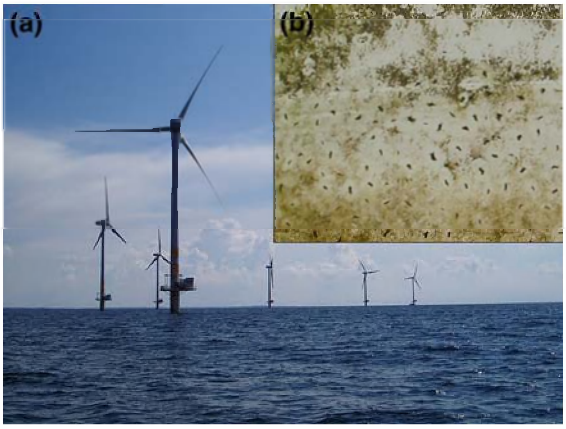

Fig. 2 (**a**) Windmills at Utgrunden 1 wind farm in the southern Kalmar Strait of the Baltic Sea where the midge *Telmatogeton japonicus* was found. (**b**) Close-up of the vertical steel foundation near the sea surface, with the rather evenly distributed larvae and larval tubes (small dark strings) of *T. japonicus* indicating a territorial behaviour. Darkened/brownish sections above and below the larvae and larval tubes are mainly green algae

T. japonicus have been done, however no samples were taken.

Weather conditions were fairly rough during collection with one meter waves. Air temperature was about 6°C and water temperature estimated to 11°C. Mean water temperature in the area is otherwise 9.2°C, ranging from −0.3 to 21.2°C. Water salinity of the surface water ranges from 6.46‰ to 7.52‰ with a mean of 6.96‰ (SMHI 2007). There is no real lunar tide in the area although changes in atmospheric pressure may alter sea level up to 0.5 m from mean level. Ice may cover the sea surface but only in harsh winters, and this has not occurred in the area for many years. Water depth at the sampling site is 7.5 m and the bottom substrate consists of small boulders and patchy sandy areas. The windmill foundations are of monopile type and made of steel with a diameter of approximately 3 m.

The dominant species in the upper zone (0–3 m above the sea level) on the windmills are the filamentous green algae *Cladophora* sp., the red algae *Ceramium tenuicorne* and the barnacle *Balanus improvisus*. Further down (3–8 m) other red algae, such as *Polysiphonia fucoides* and *Rhodocorton purpureum* together with the blue mussel *Mytilus trossulus* are the dominant species on the vertical steel foundations.

Results and discussion

Taxonomy

The collected material was identified by Y. Brodin and is considered to be *Telmatogeton japonicus* (Tokunaga 1935). The larvae and pupae agree well with *T. remanei* (Remmert 1963) and *T. gedanicus* (Szadziewski 1977) which both are considered to be junior synonyms of *T. japonicus* (Kronberg 1986; De Jong et al. 2007). Adult males show some morphological differences from *T. japonicus* described in Hashimoto (1973) and Cranston (1989). This might be a question of races rather than different species. Further studies are needed to reveal if there are one or more species of *Telmatogeton* in northern Europe.

Geographical distribution and habitat

The population of *T. japonicus* at Utgrunden 1 is the northernmost one so far reported from the Baltic Sea (Fig. 1). Previous findings are from the northern coast of Poland in the 1970s (Szadziewski 1977) and Germany in the 1960s and 1980s (Remmert 1963; Kronberg 1986, 1988), including the narrow brackish Kiel Canal.

The present findings of *T. japonicus* seem to be the first from brackish offshore areas. It is even possibly the first record of a true offshore insect in the Baltic Sea, i.e. an insect species with a complete offshore life cycle.

T. japonicus has however recently been found in large numbers on marine offshore buoys and windmills in the north-eastern Atlantic Ocean (Elsam Engineering A/S 2005; Leonhard and Pedersen 2006; Kerckhof et al. 2007). It is also recently recorded from other man-made constructions along the marine coast of Denmark and the Netherlands, such as breakwaters and concrete beachwalls against sea water inflow (Elsam Engineering A/S 2005; Boudewijn and Meijer 2007). The Atlantic African and European findings stretch from Madeira and the Azores in the south to Iceland in the north (De Jong et al. 2007), including the island Surtsey which was created through a volcanic eruption near the Icelandic coast in the 1960s (Baldursson and Ingadottir 2006). There is only one brief note indicating that the species also occurs along the Atlantic coast of Sweden (Kronberg 1988).

On a global scale *T. japonicus* is encountered now and then since the 1930s in marine coastal sea areas of the Northern Hemisphere and southwards to Australia in the Southern Hemisphere (Bugledich et al. 2007).

Biology

The present findings of *T. japonicus* on the windmills in Kalmar Strait as well as previous ones are exclusively from hard substrates, including boulders and artificial surfaces, in the splash zone several meters above and a few meters below the mean water surface. Larvae, pupae and adults are active throughout the year (Kronberg 1988; Sunose and Fujisawa 1982; Elsam Engineering A/S 2005). Flying adults can be seen also under winter conditions with an air temperature below freezing point (Sunose and Fujisawa 1982).

A prerequisite of larval development seems to be the presence of green algae (Chlorophyta) or blue-green bacteria (Cyanophyta). At Utgrunden 1 the filamentous green algae *Cladophora* sp. was partially covering the same surface as *T. japonicus*. Kronberg (1988) noted that the larvae fed on bluegreen bacteria, while others have noted feeding on green algae and diatoms (Tokunaga 1935; Sunose and Fujisawa 1982; Leonhard and Pedersen 2006).

T. japonicus can be a rapid colonizer and within a few years become a dominant species on new artificial substrates. Considerable numbers of *T. japonicus* occurred within <1.5 years on concrete blocks in the coastal zone of the Netherlands (Boudewijn and Meijer 2007). Rapid colonization is also reported from offshore windmills of south-western Denmark (Leonhard and Pedersen 2006). The seven steel windmills at Utgrunden 1 where built in 2000 and *T. japonicus* may have occurred earlier on the foundations but not noted by researchers.

Alien species?

Telmatogeton japonicus figures on the list of alien or possibly alien marine species in the European Atlantic (Hill et al. 2005; Kerckhof et al. 2007) and Polish territorial waters of the southern Baltic Sea (Solarz 2007). As for most other introduced marine species, shipping is considered to be the vector (Kerckhof *in* ICES 2005).

Whether *T. japonicus* is an alien species in the western Atlantic Ocean is not known. It is on the list of priority conservation species in the state of Carolina in the USA (South Carolina Department of Natural Resources 2005). *T. japonicus* is supposed to be indigenous in the Pacific Sea, e.g. Japan and Hawaii (Sunose and Fujisawa 1982; Englund 2001).

Thorough studies to support the view that *T. japonicus* really is an alien species in Europe seem not to be available. Its possible harmful ecological impact seems not to have been evaluated.

There are several indications that *T. japonicus* actually is an introduced species in Europe:

(A) Chironomid specialists rarely studied the coastal marine chironomid fauna themselves (Thienemann 1954), but other scientists working in marine coastal areas have sent chironomid species to expertise ever since the mid 1700s. If the conspicuous and easily recognized *T. japonicus* was present in these samples prior to the 1960s in Europe it could hardly have been missed by the expertise. Finding new unusual species has been and is still a major driving force for insect taxonomists.

(B) Of the six known marine or mainly brackish marine water species of Chironomidae found in the Baltic Sea, three are known since the 1800th century (Table 1). Two are known since the 1970s. Both are rare and morphologically similar to species known before 1900 and could easily have been overlooked in earlier taxonomic work. The sixth species *T. japonicus* was not known until the 1960s, but thereafter it has been more and more frequently observed in the marine and brackish waters of Europe.

(C) It would be surprising if the rather large, conspicuous and easily identified *T. japonicus*

Table 1 Marine or mainly marine brackish water Chironomidae found in the Baltic Sea and the decade of their discovery

Clunio marinus Haliday 1855—Baltic Sea 1850s
Clunio balticus Heimbach 1978—Baltic Sea 1970s or earlier
Cricotopus zavreli Szadziewski and Hirvenoja 1981—Baltic Sea 1970s or earlier
Halocladius variabilis Staeger 1839—Baltic Sea 1830s
Halocladius varians Staeger 1839—Baltic Sea 1830s
Telmatogeton japonicus Tokunaga 1933—Baltic Sea 1960s

Mainly based on De Jong et al. (2007)

was common prior to 1960, i.e. the period when about 75% of the presently known European species of Chironomidae were discovered (cf. Spies and Saether 2004; De Jong et al. 2007).

(D) *T. japonicus* has several features appropriate for a marine invader (Table 2). It is bound to hard marine substrates and reported also from ships' hulls (Kerckhof *in* ICES 2005). It has a high ability to survive harsh, highly variable, unpredictable and unnatural conditions which are features advantageous for long transportation by ships. It is active throughout the year which increases the chances to establish contact with ships while they are passing or filling up ballast water.

(E) Figure 1 shows that all findings of *T. japonicus* in the Baltic Sea are near important ports for international ship transportation. The first record in Europe was just north of the major shipping port Kiel in Germany, and Remmert (1963) suspected *T. japonicus* to be introduced by shipping. Support for this view was gained from the later frequent findings of the species along the Kiel Canal (Kronberg 1988). The Kiel Canal is an important vessel transportation seaway that connects the eastern Atlantic with the Baltic Sea.

To summarize, *T. japonicus* should be looked upon as a quite likely alien species in the Baltic Sea and Northern Europe. There are good reasons to take this into consideration when updating lists of alien species of the Baltic Sea (Nobanis 2007) and Sweden (Informationscentralerna för Bottniska viken, Egentliga Östersjön och Västerhavet 2007). So far, no insect species figures on these lists.

Ecologically harmful?

There are probably no reasons to consider the common presence and dominance of *T. japonicus* at the wind farm Utgrunden 1 in the Kalmar strait and other artificial hard substrates in brackish or marine habitats as harmful. It could even be advantageous for native species as *T. japonicus* might be important as bird food especially in autumn and winter when other insects are uncommon and food generally is sparse or less available (Sunose and Fujisawa 1982). Observations in the Netherlands have shown that migrating wader birds (Charidriidae) use *T. japonicus* as an important source of food (Boudewijn and Meijer 2007).

Table 2 Adaptability and tolerance features of *Telmatogeton japonicus*

Adaptability
Dark colour: A common feature of insects and other small organisms in cold climate.
Short antennae of adults: Some marine and high-altitude Chironomidae have short antennae lacking the otherwise common plume. This is probably an adaptation to cold and windy conditions.
Living mainly above the water surface: This means that predation by fish and other mainly submerged species is limited. Offshore living in windy and wavy conditions on windmills or buoys will probably also reduce predator pressure from flying animals such as birds, other insects and bats.
Emergency of adults throughout the year: Frequent emergency also during winter is a way to reduce the impact of several predators such as other insects, spiders, mites, birds and bats. Predation might however be substantial during the bird migration seasons in spring and autumn.
Adhesion tubes and girdles: The larval tubes and girdles are firmly adhered to the substrate and offers protection against predation as well as strong waves and water currents.
High colonization ability: Among the first to colonize and dominate new hard substrates such as concrete blocks, buoys and windmills.
Dormancy: Suspected but not shown. Weeks or months of dormancy under dry, cold or other stressing environmental conditions is a common feature among chironomids, in one case as much as 17 years (Adams 1983).
Tolerance limits
Salinity: Slightly brackish (below 4‰) to fully marine (35‰) conditions.
Temperature: Below freezing point to about +35°C. Active as adults and larvae also during winter periods.
Nutrient level: Moderately eutrophic to strongly eutrophic conditions.
Humidity: Ability to live under unpredictable humidity conditions ranging from total submerged conditions to several days or weeks of dry terrestrial conditions.
Wind: Probable ability to withstand stormy conditions. Emergence of adults however mainly during periods of relatively calm sea periods.

Based on observation done within the present study and information gained mainly from Sunose and Fujisawa (1982), Kronberg (1986, 1988), Elsam Engineering A/S (2005) and Boudewijn and Meijer (2007), but also Tokunaga (1935), Wirth (1949), Remmert (1963), Neumann (1976), Szadziewski (1977), Robles (1984), Schnell and Aagaard (1996), Colbo (1996), Murray (1999, 2000), Englund (2001), Kirk-Spriggs et al. (2001), Dong Energy et al. (2006), Leonhard and Pedersen (2006), Kerckhof et al. (2007)

On the other hand *T. japonicus* might also cause effects that are not welcome. The clearly more frequent findings of the species since the turn of the present century and the still increasing number of offshore wind farms in the Baltic Sea could indicate that the species is becoming more common and expanding its geographical distribution. *T. japonicus* was noted from three European countries (Germany, Poland and Sweden) until to the mid 1990s, but thereafter from eight new countries (Portugal, Ireland, Belgium, the Netherlands, England, Denmark, Norway and Iceland).

Harmful effects could occur if this means substantially increased populations of *T. japonicus* also in marine or brackish habitats which are of concern for protection of native species. As summarized in Table 2 *T. japonicus* can reach domination, it has a high capacity to colonize new areas and high endurance of harsh environmental conditions including severe eutrophication. The strongly eutrophied southern Baltic Sea may offer appropriate living conditions for the species.

The continuous increase of made-made constructions in marine and brackish waters, especially wind farms (IEA 2006), may mean a second chance for previously introduced species. Kerckhof et al. (2007) addressed the phenomenon that several alien marine species after years of illusory disappearance since their first observation now have become much more frequent in the European Atlantic Ocean. Their list includes barnacles, algae, crabs and mussels. *T. japonicus* might be added to this list. Kerckhof et al. (2007) did in fact note that *T. japonicus* is a common species in Belgian waters since its first observation in 2005.

Telmatogeton japonicus should be of interest to monitoring activities in Europe, particularly in marine and brackish hard bottom habitats, including along the Baltic Sea coast. It is already within the marine monitoring program for offshore wind farms in Denmark (Elsam Engineering A/S 2005; Dong Energy et al. 2006) .

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