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Towards clarifying the presence of alien algae in inland waters – can we predict places of their occurrence?

Elżbieta Wilk-Woźniak & Kamil Najberek

Institute of Nature Conservation PAS, al. Mickiewicza 33, 31-120 Kraków, Poland; e-mail: wilk@iop.krakow.pl

Abstract: Small algae are the trophic basis in both marine and freshwater ecosystems. The identification of tiny microorganisms and place of their origin is laborious but necessary. This paper consists of a literature review of 17 species of planktonic algae, with a discussion of taxonomic problems. We also clarify whether these 17 species are non-native, invasive or cryptogenic species, with an indication whether they had been recognised as 'alien' in Europe. According to our observations, areas colonized by small and alien algal species, were anthropogenically altered. There were: systems with heated waters ('heated islands'), which imitated tropical conditions; highly eutrophic to hypereutrophic water ecosystems, easily colonized by alien species, fishponds with intense fish cultivation, where alien species of fish are/ had been introduced, which carried also other alien organisms; and inland water ecosystems with high salinity or high conductivity e.g. pits inundated by mine waters, imitating sea or brackish conditions acting as hubs of migration of alien species adapted to brackish or saline waters. We have prepared a map showing areas inhabited by alien species, both of documented places and hypothetical ones, where we would expect alien species to occur.

Key words: anthropogenic impacted habitats; cryptogenic; invasive; non-native; planktonic algae

Introduction

Biological invasions can change the structure and function of ecosystems (Strayer 2012). Invasive organisms[1,2,3] cause ecological impacts on different levels: genetic, individual, population, community, ecosystems, landscape, both at regional and global scale (Lockwood et al. 2007). The level of invasions at the regional scale may be quantified as the number of alien species (Pyšek et al. 2010), because the spread of non-native species bases on the same mechanisms what invasions in their earlier stages (Lockwood et al. 2007). Hence knowledge about the occurrence and spread of non-native species is crucial for deriving solutions for potential invasions, changes of biodiversity and proper conservation, both marine and freshwater ecosystems. Such knowledge serves as basis for prediction of changes in water habitats, and the development of conservation methods for proper conditions of water ecosystems.

Since microalgae are the basis of the aquatic food web, changes in algal communities are reflected in the succeeding trophic levels such zooplankton, invertebrates, fish, etc. Therefore, it is important to gather data about the occurrence of alien species of microalgae. The current database of alien and invasive species (e.g., DAISIE http://www.europe-aliens.org/speciesSearch.do, NOBANIS http://www.nobanis.org/Search.asp, PROTISTS http://protists.gbif.de/protists/) is not sufficient. The information included in the database is not always reliable and can cause misunderstanding and misinterpretation, and needs critical review. The problem of alien and invasive alien species among microalgae is urgent; however our knowledge is still not sufficient. In freshwater ecosystems species from two groups, cyanobacteria and diatoms, are the most often presented as the examples of non-native and invasive microalgae (Padisák 1997; Blanco & Ector 2009; Falasco & Bona 2013). Today, there are more papers about non-native and invasive algae in Europe but lot of them are publish in local journals or just exist as manuscripts, both of them difficult to find and use.

The aim of the paper is a review of non-native species of microalgae found in inland waters including information on whether they are alien for Europe or not and, if needed, with taxonomical comments.

Based on documented places of existence of alien species in Poland, we have prepared a map of areas, where alien species of microalgae can hypothetically ex-

[1] Invasive – 'refers to established alien organisms that are rapidly extending their range in the new region. (This is usually associated, although not necessarily for an organism to qualify as invasive, with causing significant harm to biological diversity, ecosystem functioning, socio-economic values and human health in invaded regions)'.

[2] Alien – 'an organism occurring outside its natural past or present range and dispersal potential, whose presence and dispersal is due to intentional or unintentional human action'.

[3] Cryptogenic – 'a term used for species of unknown origin or means of arrival, which cannot be ascribed as being native or alien'. All definitions after Walther et al. 2009.

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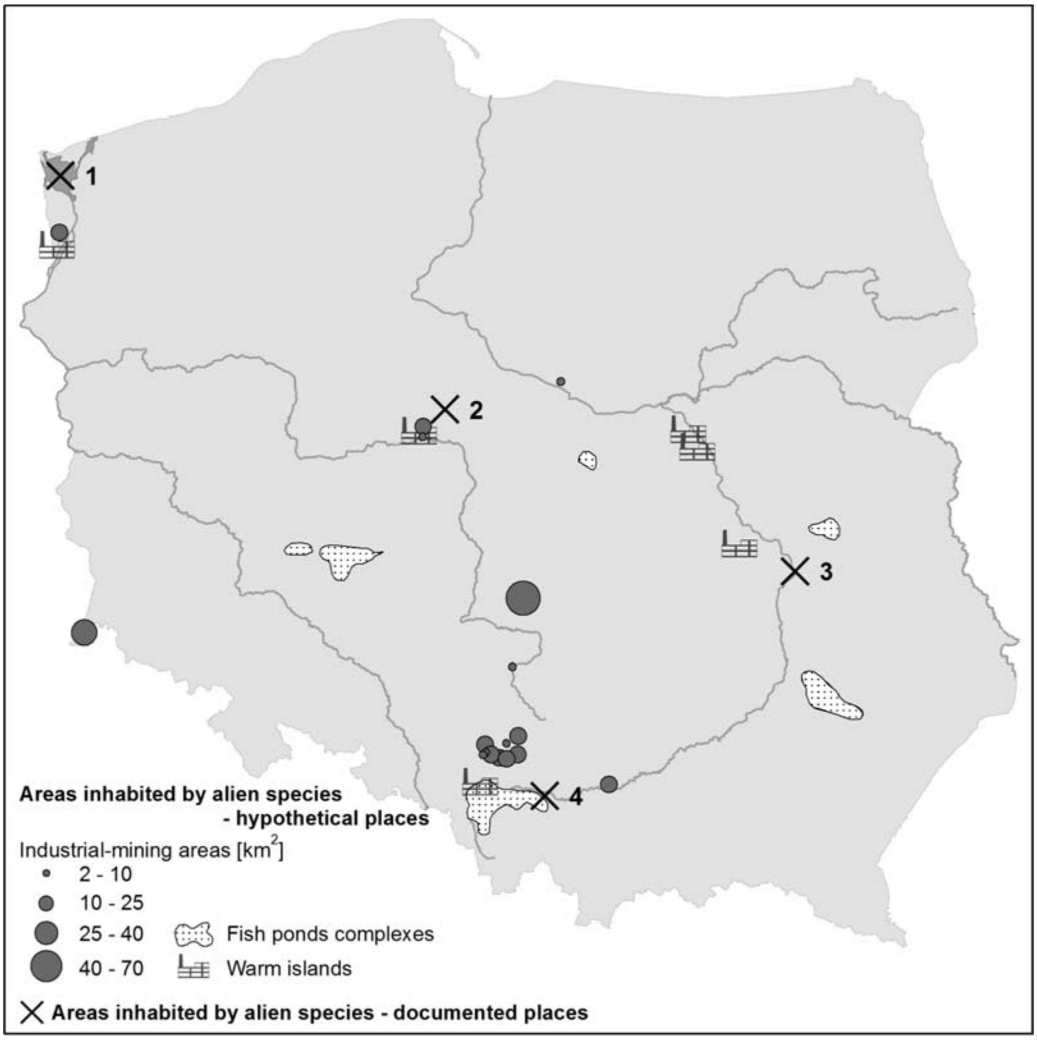

Fig. 1. Documented and predicted areas of existence of alien algae species in Poland: 1 – Szczecin Lagoon; 2 – Konin Lakes ecosystems with Pątnowskie Lake; 3 – oxbow lake of the Vistula River; 4 – fishponds in Zator and Spytkowice (Oświęcimska Valley).

ist, but have not been reported so far, because these places have not been investigated yet. Accepting the statement that non-native species possess a broad range of ecological requirements and they are more often found in the human impacted habitats, we suggest that occurrence of alien species might be better predicted all around the world.

Material and methods

The paper is a literature review. Searching for papers and journals we used the most popular scientific bases: ISI Web of Knowledge, Scopus, and Google Scholar. The key words used for searching were following: alien, invasive, cryptogenic, algae, phytoplankton, freshwater, marine, anthropogenic impacted waters. To confirm the place of origination of invasive or alien algae and to compare range of occurrence we used AlgaeBase (Guiry & Guiry 2012) The AlgaeBase was used also to check the proper taxonomical position every species. We selected only those papers to which we had no any objections that species were identified correct (e.g., photos were included or the identification was consulted with specialist). For construction of the map (Fig. 1) we used following sources: fish ponds complexes were created after Dobrowolski (1995) and industrial-mining areas after Podemski et al. (1994) and Richling et al. (1995). Map was created in ArcGIS 10.1 program.

Results

There were chosen 17 species which occurred in Polish inland waters: 7 species belong to cyanobacteria, 2 species belong to green algae, 6 species belong to diatoms, and 2 species belong to dinoflagellate (Tab. 1). The water ecosystems which are hot spots for non-native species in Poland were shown on the Fig. 1. They included: 1. Szczecin Lagoon – there are located three harbours, and there is a path between two harbours Szczecin – Świnoujście; 2. Konin Lakes ecosystems – waters of lakes are affected by heated waters as they are used as cooling water for a power station, 3. oxbow lake of the Vistula River affected by municipal and industrial wastes, and heated waters influx from Fertilizer Factory; 4. fishponds in Zator and Spytkowice (Oświęcimska Valley) covering great areas, where alien fish were introduced. Quite a few species presented in the paper were found in those places, e.g., *Cylindrospermopsis raciborskii, Coelastrum polychordum, Conti-*

Table 1. Alien, invasive and cryptogenic species in Polish waters.

Name	Native area	Introduced area (in Europe)	Human pressure of the newly invaded waters in Poland	Year of the first observation in Poland	Status
CYANOBACTERIA					
Anabaenopsis cunningtonii Taylor	Africa, Lake Tanganyika, widespread in tropical and subtropical regions (Hindák 1988)	Slovakia, Belarus and northern Germany (Hindák 1988), Greece (Vardaka et al. 2005), Hungary (Padisák & Reynolds 1998), and in southwestern France (Cellamare et al. 2010)	Dymaczewo Lake – a recreational, highly eutrophic lake (western part of Poland) (Zagajewski et al. 2009)	2005	Alien species in European waters
Anabaena minderi Huber-Pestalozzi[1]	Ponto-Caspian region, Caspian Sea (described as *A. bergii* by Orlova and Rusakova 1999)	Slovakia (Hindák 2000), in Austria and Slovenia (after Koreivienė & Kasperovičienė 2011)	A sand-pit lake created after sulphur mining (eastern part of Poland) (Wilk-Woźniak & Żurek 2006)	2000	Alien species in European waters
Cuspidothrix issatschenkoi (Usačev) Rajaniemi et al. (*Aphanizomenon issatschenkoi*)	Caspian region from the Caspian Sea and the Sea of Azov (Kaštovský et al. 2010)	Slovakia (Hindák 1992), Czech Republic (Kaštovský et al. 2010), and Germany (Täuscher 2011)	Lake Gardno, northern part of Poland, which is a shallow lake influenced by the Baltic sea waters (Strzelecki & Półtorak 1971)	1971	Alien invasive species in European waters
Cylindrospermopsis raciborskii (Woloszynska) Seenayya & Subba Raju	Indonesia-Java	currently known in many countries in Europe (Komárek & Komárková 2003)	artificially heated water of Lake Pątnowskie (Burchardt 1977) into which water from a power plant was discharged[2]	1973	Alien invasive species in European waters
Planktothrix rubescens (De Candolle ex Gomont) Anagnostidis & Komárek	northern temperate zone (Komárek and Anagnostidis 2005)	It is found mostly in the western alpine region (Kaštovský et al. 2010). Its spreading in lowland waters might indicate fast colonization of different habitat types as was the case in the diatom *Didymosphaenia geminata*, which currently is an alien invasive species in North America, Australia and New Zealand (Whitton et al. 2009)	Piaseczno Lake, which is a highly eutrophic lake in eastern Poland (Krupa & Czernaś 2003).	1986	Alien species in Polish waters

[1]This species is taxonomically confused. Previously *A. minderii* Huber-Pestalozzi = *A. bergii* var. *limnetica* Couté et Preisig. According to Komárek & Mareš (2012) *A. minderi* together with *Anabaena bergii* Ostenfeld and *Aphanizomenon ovalisporum* Forti belong to the *Anabaena*-like cluster I. Zapomělová et al. (2012) created a new genus *Chrysosporum* and shifted *Anabaena bergii* Ostenfeld as *Chrysosporum bergii* comb. nova. *A. bergii* Ostenfeld (*Chrysosporum bergii* Zapomelova et al.) is known: a) from the Czech Republik (Kaštovský et al. 2010), Slovakia (Hindák 2000), Germany (Stüken et al. 2006), in Poland first (Kokociński et al. 2009), Belarus and Ukraine (after Koreivienė & Kasperovičienė 2011).; b) As *A. bergii* var. *limnetica* from Lithuania (Koreivienė & Kasperovičienė 2011); c) As *A. bergii* var. *minor* from Austria and Ukraine (after Koreivienė & Kasperovičienė 2011).

[2]Pątnowskie Lake is included into Konin Lakes System that is affected by heated waters as the lakewater is used as cooling water for a power station. In those lakes were found a number of alien species belonging to different groups. These are: copepod *Acanthocyclops americanus,* oligochaete *Aeolosoma headleyi,* fish *Aristichthys nobilis,* Asian fish tapewarm *Bothriocephalus acheilognathi,* oligochaete *Branchiura sowerbyi,* fish *Carassius auratus auratus,* fish *Carassius auratus gibelio,* Crustacea *Chaetogammarus ischnus,* amphipod *Chelicorophium curvispinum,* hydroid *Cordylophora caspia,* fish *Ctenopharyngodon idella,* algae *Cylindrospermopsis raciborskii,* fish *Cyprinus carpio,* Platychelmintes *Dasyhormus lithophorus,* mollusc *Dreissena polymorpha,* planarian*Dugesia tigrina,* snail *Ferrissia clessiniana,* aquatic weed *Hygrophila polysperma,* fish *Hypophthalmichthys molitrix,* fish *Ictiobus niger,* tapewarm *Khawia sinensis,* mollusc *Lithoglyphus naticoides,* snail *Melanoides tuberculatus,* snail *Menetus dilatatus,* Crustacea *Notodromas persica,* fish *Oreochromis niloticus,* freshwater briozoa *Paludicella articulata,* snail *Physella acuta,* freshwater bryozoa *Plumatella emarginata,* freshwater bryozoa *Plumatella fungosa,* mollusc *Potamopyrgus antipodarum,* nemertea *Prostoma kolasai,* fish*Pseudorasbora parva,* Chinese pond mussel *Sinanodonta woodiana,* flatwarm *Stenostomum brevipharyngium,* flatwarm *Stenostomum predatorium,* flatwarm *Stenostomum pseudoacetabulum,* flatwarm *Stenostomum uronephrium,* slider turtle *Trachemys scripta,* entoproct *Urnatella gracilis,* submerged macrophyte *Vallisneria spiralis* (Najberek & Solarz 2011).

Table 1. (continued)

Name	Native area	Introduced area (in Europe)	Human pressure of the newly invaded waters in Poland	Year of the first observation in Poland	Status
Raphidiopsis mediterranea Skuja[3]	subtropical range (Kaštovský et al. 2010)	Czech Republic (Kaštovský et al. 2010), Slovakia (Maršálek et al. 2000), and Lithuania (Kasperovičiené et al. 2005)	Dymaczewo Lake – a recreational, highly eutrophic lake (western part of Poland) (Zagajewski et al. 2009)	2004–2006	Alien invasive species in European waters
Sphaerospermopsis aphanizomenoides (Forti) Zapomélová (*Aphanizomenon aphanizomenoides* (Forti) Hortobágyi & Komárek or *Anabaena aphanizomenoides* Forti)	A lake in Anatolia (Geitler 1932) and has predominantly been reported from the tropical and subtropical regions (Zapomělová et al. 2012)	Czech Republic (Horecká & Komárek 1979), Slovakia (Hindák 2000), and Germany (Stüken et al. 2006)	highly eutrophic to hypereutrophic lakes in the Wielkopolska region (western Poland) in 2002 (Stefaniak & Kokociński 2005).	2002	Alien species in European waters
GREEN ALGAE					
Coelastrum polychordum (Korshikov) Hindák (*Coelastrum reticulatum* v *polychordum* Korshikov)[4]	India (Kaštovský et al. 2010), Spain, Australia and New Zealand, Brazil, and Taiwan (Guiry & Guiry 2012)	all around the Europe	Konin Lakes System – heated waters (see *Cylindrospermopsis raciborskii*)	1970 (Burchardt & Dąmbska 1976)	Alien species in European waters
Pediastrum simplex Meyen[5]	Bangladesh, Turkey, Japan, Florida, China, Albania, Egypt and Costa Rica (Kaštovský et al. 2010)	all around the Europe	many waters in Poland, mostly eutrophic or hypetrophic	no information	Alien species for Northern part of Europe
DIATOMS					
Conticribra guillardii (Hasle) Stachura-Suchoples et D.M. Williams (*Thalassiosira guillardii* Hasle)	brackish waters in the Baltic Sea (Gulf of Finland),	Norway, Sweden, North America (Ohio and Oregon), Japan (Guiry & Guiry 2012), Russia (Wojtal & Kwandrans 2006), Hungary, and the Iberian Peninsula (Kiss et al. 2012)	an anthropogenically altered Vistula oxbow lake ('Rozlewisko') in Central Poland, heavily contaminated with heated waters (Wilk-Woźniak & Ligęza 2003)	1999	In our opinion this is an alien species in European inland waters
Cyclostephanos delicatus (Genkel) Casper & Scheffler	the northern hemisphere, but its accurate range is unknown (Wojtal & Kwandrans 2006)	Slovakia (Hindák & Hindáková 2002), northern Germany (Casper & Scheffer 1990), and in the Czech Republic (Kaštovský et al. 2010)	the Wolnica Bay, a highly eutrophic part of the artificial dam reservoir (Wojtal et al. 2005)	2000	In our opinion this is a cryptogenic species
Discostella woltereckii (Hustedt) Houk & Klee (*Cyclotella woltereckii* Hustedt)	pantropical diatom species (Day et al. 1995)	Germany (Klee & Houk 1996), in Slovakia (Hindák & Hindáková 2003), and in the Czech Republic (Kaštovský et al. 2010)	an anthropogenically altered Vistula oxbow lake ('Rozlewisko') in Central Poland, heavily contaminated with heated waters (Wilk-Woźniak & Ligęza 2003)	1999	Alien species in Polish waters

[3] *Raphidiopsis* is taxonomically still problematic genus. Komárek and Mareš (2012) stated: 'It is very probable that young filaments of *Cylindrospermopsis raciborskii* without heterocytes are often misinterpreted and identified as *Raphidiopsis mediterranea*.' Indeed, there are studies which showed that *R. mediterranea* represents a non-heterocytous life-cycle stage of *Cylindrospermopis raciborskii* (Moustaka-Gouni et al. 2010)
[4] This name is currently regarded as a taxonomic synonym to *Hariotina polychorda* (Korshikov) E. Hegewald.
[5] This name is currently regarded as a taxonomic synonym to *Monactinus simplex* (Meyen) Corda

Table 1. (continued)

Name	Native area	Introduced area (in Europe)	Human pressure of the newly invaded waters in Poland	Year of the first observation in Poland	Status
Gyrosigma fasciola (Ehrenberg) Cleve	a brackish or marine diatom species	the Gulf of Finland, Gulf of Riga (Hällfors 2004), southeast Asia, Great Britain, Romania, Spain, North America, South America, Antarctic and subantarctic islands (King George) (Guiry & Guiry 2012)	freshwater 'Krajskie' Vistula oxbow lake (Oświęcimska Valley, southern Poland). This oxbow is close to fish-ponds with intensive fish cultivation, where alien species of fish were introduced[6].	2011	Alien species in European freshwaters
Skeletonema potamos (Weber) Hasle in Hasle & Evensen	—	according to Kaštovský et al. (2010) has never been reported in central Europe but according to studies, which has been done in Poland this species exists in Europe (Wojtal & Kwandrans 2006).	freshwaters in Wyżyna Krakowsko-Częstochowska upland during investigations in 1993–2005 (Wojtal & Kwandrans 2006).	—	In our opinion this is a cryptogenic species
Thalassiosira duostra Pienaar	Republic of South Africa	the Danube River, Spain and Brazil (Wojtal & Kwandrans 2006).	it is only known from an anthropogenically altered section of a stream in southern part of Poland (Wojtal & Kwandrans 2006).	1990s	Alien species in European waters
DINOFLAGELLATE					
Peridiniopsis kevei Grigorszky et Vasas in Grigorszky	the natural range of this dinoflagellate species is unknown	Hungary, Austria, Italy, Germany, France, Romania, Slovakia, (Grigorszky et al. 2001), and Czech Republic (Kaštovský et al. 2010)	it was found in different parts of the country, mostly in the oxbow lakes (Owsianny & Grabowska 2009; Messyasz et al. 2011)	2004	In our opinion this is a cryptogenic species or native for Europe
Peridinium gatunense Nygaard	Australia, New Zealand, Brazil, China and Singapore (Guiry & Guiry 2012)	Sweden	all around the Poland but especially abundantly in north-western part of Poland (Owsianny & Grabowska 2009)	1980s	Alien species in European waters

[6]Apart from *Gyrosigma fasciola*, in that oxbow lake were frequently found invasive species from different groups of organisms: water plant *Elodea canadensis*, crayfish *Orconectes limosus*, the Chinese pond mussel*Anodonta woodiana*, a small, left-handed or sinistral, air-breathing freshwater snail*Physella acuta*, and fish *Ctenopharyngodon idella.*

cribra guillardii, Discostella woltereckii, Gyrosigma fasciola (first observations in Poland), and *Peridiniopsis kevei.* Others species were observed in places close the above mentioned ecosystems.

Discussion

Based on literature review of Polish freshwater ecosystems, we present a map with the documented areas of alien planktonic algal species and a map of areas in Poland with highest probability of existence of alien species (Fig. 1). The map shows areas where large numbers of alien species from different groups have been observed and the hypothetical areas where alien phytoplankton species may occur due to their ecological requirements, e.g., higher temperature of water, high concentrations of ions etc. Areas that fulfil all requirements and show similarities to different biogeographical regions to be such an hypothetical area exist all around the world and include:

– the (originally natural) resource basins (industrial-mining areas, e.g. coal basin, sulphur basin etc.), where after exploitation pits are inundated by mine waters, and generate conditions different from natural ones, promoting the existence of alien species. Such types of waters create conditions similar to brackish or saline waters, and may promote existence of species originated from sea or oceans localities,

– lakes, oxbow lakes, rivers affected by heated waters, which may imitate conditions of tropical regions, and may be good places for the 'first visit' of alien species originating from warm ecosystems,

– fishponds covering great areas, where aquaculturing has been conducted since the Middle Ages, and where alien fish were introduced, carrying many alien species from different groups, thereby extending the occurrence of alien species (Fig. 1).

We are aware that the list of alien planktonic algae is not complete. It is difficult to rate microbial species as 'alien'. Sometimes it is more adequate to categorise microbial species as 'cryptogenic', while others need more careful studies of their origin and range of conditions, and many of them need taxonomical revision (see *Peridiniopsis kevei*, *Anabaena minderi*, *Raphidiopsis mediterranea*). Why is it important to conduct studies of alien species? Many of them are found for the first time in the water systems that are under anthropogenic pressure. It is true not only for small planktonic algae, since other studies confirm the same opinion. For example, Pyšek et al. (2010) studied alien plant and insect species, and they found that their highest numbers were found in urban, cultivated or man-made habitats. Some ecosystems are more susceptible to colonisation by alien species (Strayer 2012) and these habitats are anthropogenically impacted Knapp & Kühn (2012) such as ecosystems affected by industrial and municipal wastes, heated waters, aquaculturing, quick rise of trophy because of strong tourist or agriculture pressure etc. Alien species thrive in severely human impacted areas because altered conditions facilitate they dispersal, there is no competition by native species under severely changed habitats, and because invasive species are good colonizers of newly created habitats. We observed the same phenomena: a high number of alien species was found in the anthropogenically impacted systems (see *Gyrosigma fasciola*, *Cylindrospermopsis raciborskii,* and *Coelastrum polychordum*). For the greater part of these species, the described areas may be use as shelter or hubs. When such species is ready to expand its range after an "adapting period", they move to reservoirs with natural water conditions in other regions or countries (e.g. with fry or by birds). This model of expansion is actually observed in other groups of organisms in Poland – e.g. Chinese mussels *Sinanodonta woodiana* (Najberek et al. 2011, Najberek et al. 2013) and is likely that it could be also used by algae.

Human impact causes strong changes in aquatic ecosystems, which promote the success of alien species (Dukes & Mooney 1999; Strayer 2012). Proper selection of types of water habitats which are susceptible for colonisation by alien species may be useful for the assessment of areas at risk of invasion by alien species, of biodiversity and of proper conservation of aquatic habitats.

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