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·综述·

Invasive macrozoobenthic species: are they a threat to the aquatic communities of German water bodies?

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Abstract: Macrozoobenthic invasion is a common phenomenon which appears throughout the world. Humans travel worldwide transporting materials from one continent to another. This enables many aquatic species to breach natural boundaries and invade environments in other regions and continents. With modern travel the number of species moving between different regions has increased considerably and so the number of successful aquatic invasions has increased. To be a successful invading species，there are some necessary traits. Mobility，small body size，adaptability and a high reproductive rate for example，would contribute to a successful cross – regional invasion. But the new host environment must fit some accommodating criteria. Environments that are depleted of their historical species due to human impact damage，may make little or no resistance to new organism invasions. German water bodies are under serious stress from human impact. Many water bodies are irreparably disturbed and some are now totally artificial habitats. These water bodies are a complex network of connecting rivers and canals that facilitate the spread of invasive macrozoobenthic species. Our literature research and our own investigations show that water bodies，rivers and streams that are under stress from human impact，or damaged by direct interference，are more vulnerable to aquatic invasive species alien to the local natural environment，than water bodies more closely aligned to their original，natural conditions.

Key words: macrozoobenthic; community; invasive species; Germany; water body

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1 Invasion is a common phenomenon

"PANTA RHEI"，expressed by the ancient Greek philosopher Heraklit，describes the character of nature: "Everything is in flow". Every biological system is open，dynamic and very complex. This means，for example，that species thriving in an environment can vanish，while others can invade and flourish. There is no rule which can predict or qualify these changes. In principle，changeability is the nature of nature，and the essential character of ecosystems is instability and inhomogeneity[1]. Invasion is a normal phenomenon which can appear any time，and anywhere. Especially after dramatic ecological occurrences，such as land slides，volcanic eruptions and prolonged climatic changes. These events could adversely affect the prevailing conditions，resulting in the disappearance of one species and the appearance of another.

Because of a long geological and evolutionary history，our planet has an enormous diversity of plants，animals，and micro-organisms throughout each continent and ecosystem. Geographical barriers have ensured so that most

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species remain within their region，thus resulting in a much greater variety and species richness across the planet，than would have been the case if all land masses were part of a single continent[2]. This historical biogeographical framework provides the basis for defining native and alien species. It is also important to recognize that biogeography is dynamic. Species expand and contract their ranges of ecosystems and ecosystems change[3]. As humans increase speed and frequency of global travel and move more materials across international boundaries，the probability of transporting species increases dramatically. Humans have created a world without borders for many species[4] and rates of human-caused species invasions are far greater than the rates that would have occurred naturally[5]. But what kind of species do we call"invasive alien species"? In Germany we call animals and plants that arrived since 1492 (disembarkation of Columbus in Central America) as invasive species. Schaefer[6] defined them as"species which are introduced from humans，from other continents or climate zones and often only able to establish at particular areas. Often they are part of nature near ecosystems."

In this text，we concentrate on aquatic invasive alien species the macrozoobenthic species (invertebrate animals，which are taller than 1 mm，live on or in the sediment or on the vegetation - temporary swimming[7]). There are some traits in cosmopolitan species which improve the chances of success：Small body size which enables invasion by use of many different modes of transport，durability allowing the species to survive prolonged periods without water，high reproductive rate (r-strategists) that could overwhelm any predator in the new environment，mobility that enables active migration，euryoecious traits of adaptability and flexibility of aquatic conditions and food variation[8-11].

2 Aquatic invasive alien species (AIAS) in the German water bodies

2.1 Aquatic invasive alien species (AIAS)

The AIAS in the German waterways show many of those special traits which help them settle successfully. Table 1 summarises the AIAS found in German freshwater since 1492 with their medium for spreading and their special traits.

The freshwater snail *Ferrissia wautieri* is able to build a septum，which makes it resistant to dry periods. In this way many snails and mussels are able to survive transportation even in the air，for example with water birds[12]. A high and effective productive rate can be found in *Dreissena polymorpha* and *Corbicula fluminea*. They have planktonic larvae which are able to spread long distances in the water flows and currents of streams and rivers. *Ferrissia wautieri* and *Potamopyrgus antipodarum* are parthenogenetic species and *Viviparus viviparus* shows sexual dimorphism，which enables these species to reproduce even without high abundances. Several of the AIAS are able to migrate actively. The small snail *Potamopyrgus antipodarum* is able to migrate against a water flow of 30 cm/h at a current of 0.23 m/s[13]. Positive rheotaxis and other active migration habits are also found in most crustacean species. One important trait is their salt tolerance. Many rivers are impacted with organic wastewaters and mine waters and therefore have an increased salt content. Often native species are not able to tolerate higher salt concentrations，but several of the AIAS are (see table 1). Many European rivers are affected by power plant water outlets that cause artificially variable temperature ranges. Here again，several AIAS，often from the Mediterranean，can tolerate those temperatures (see table 1)，while native species need a special minimum temperature in winter for breeding or cannot stand higher temperatures in summer. Conditions，characteristics or events which facilitate or cause the spread of AIAS must be individually identified. There are natural conditions and characteristics such as high mobility and high migration activity，tolerance to varying conditions，climatic changes，and passive transport via birds or fishes.

Table 1 Aquatic invasive alien species (AIAS) found in German inland waters*

Taxa	Origin	Medium for spreading	Speciality
Coelenterata			
Cordylophora caspia	Pontocaspis	Navigation	halotolerant
Craspedacusta sowerbyi	E-Asia	Aquaristics, Navigation, Birds	termophilous
Turbellaria			
Dendrocoelum romanodanubiale	Pontocaspis	Navigation, Birds	
Dugesia tigrina	N-America	Aquaristics	ruryoecious
Gastropoda			
Ferrissia wautieri	SE-Europe	Navigation, Birds	resistant to dehydration
Lithoglyphus naticoides	Pontocaspis	Navigation, Birds, Fish	pelophilous
Physella acuta	SW-Europe	Navigation, Aquaristics, Birds	ruryoecious
Physella heterostropha	N-America	Aquaristics	
Potamopyrgus antipodarum	Newzealand	Navigation, Birds, Fish	halotolerant
Viviparus viviparus	E-Europe	Navigation, Birds	pelophilous
Bivalvia			
Congeria leucophaeta	Asia	Navigation	halotolerant
Corbicula fluminea	N-America	Navigation	halophilous
Dreissena polymorpha	Pontocaspis	Navigation	halotolerant
Oligochaeta			
Branchiura sowerbyi	S-Asia	Aquaristics, Navigation	temperature-tolerant
Hirudinea			
Caspiobdella fadejewi	Pontocaspis	Navigation, Fish, Migration	
Barbronia weberi	S-Asia	Navigation	thermophilous, euryoecious
Polychaeta			
Hypania invalida	Pontocaspis	Navigation	pelophilous, halotolerant
Crustacea			
Atyaephyra desmaresti	Mediterranean	Navigation, Migration	phytophilous eurythermic, halotolerant
Corophium curvispinum	Pontocaspis	Navigation, Migration	halotolerant
Crangonyx pseudogracilis	N-America	Navigation, Birds	
Dikerogammarus haemobaphes	Pontocaspis	Navigation, Migration	
Dikerogammarus villosus	Pontocaspis	Navigation, Migration	euryoecious
Echinogammarus berilloni	Mediterranean	Navigation, Migration	euryoecious
Echinogammarus ischnus	Pontocaspis	Navigation, Migration	halotolerant, eurythermic
Echinogammarus trichiatus	Pontocaspis	Navigation, Migration	
Eriocheir sinensis	E-Asia	Navigation, Migration	halotolerant, eurythermic
Gammarus tigrinus	N-America	Exposure, Navigation, Migration	halotolerant, eurythermic
Hemimysis anomala	Pontocaspis	Exposure, Navigation, Migration	halotolerant
Jaera istri	Pontocaspis	Navigation, Migration	halotolerant
Limnomysis benedeni	Pontocaspis	Navigation, Migration	
Obesogammarus obesus	Pontocaspis	Navigation, Migration	
Orchestia cavimana	Ponto-med	Migration	halotolerant
Orconectes limosus	N-America	Exposure, Navigation, Migration	euryoecious
Pontogammarus robustoides	Pontocaspis	Navigation, Migration	
Proasellus coxalis	Mediterranean	Navigation, Migration	halotolerant
Proasellus meridianus	W-Europe	Navigation, Migration	halotolerant
Rhithropanopeus harrisii	N-America	Navigation, Migration	euryhalinous
Bryozoa			
Pectinatella magnifica	N-America	Navigation, Migration	thermophilous
Porifera			
Eunapius carteri	Africa	Navigation	thermophilous

* Information of this table cited from: [14 – 68]

Human impact may also cause AIAS through species introduction for fisheries, introduction via aquaristics, passive transport via ship bodies and ballast water, environmental changes in rivers, streams and water bodies[10, 14]. For long distance transport of aquatic invertebrates, ballast water is the most important factor and some kind of ecological roulette[69]. The introduction via ballast water has been proven for *Dreissena polymorpha* (from the Pontokaspis to USA and Central Europe), *Gammarus tigrinus* (from USA to UK), *Eriocheir sinensis* (from China to Germany), *Rhithropanopeus harrisii* (from North Atlantic to the Netherlands), *Crangonyx pseudogracilis* (from England to Wales).

Often invasion by animal alien to an environment is seen as a danger for the continuity of the old biocoenosis. But before reaching this conclusion the reason for the successful invasions should be examined. Predicting which species will invade and the effects of the invasion is difficult[70]. Saturated biocoenosis is normally stable and the ecological niches are filled with specialised species which are very well adapted to those conditions. Invaders are only successful, if they find an empty niche or if they are better suited to the environment.

Often, human impact causes great changes in the environment of aquatic ecosystems (see above). If a native species is unable to adapt to the new conditions, it would become extinct and consequently open an opportunity for an AIAS. The formerly saturated biocoenosis changes to unsaturated, with niches which are open to a new species. Now it's left to chance as to which species arrive first, and which species are able to establish themselves in the new conditions. AIAS often have the advantage, because most of them have a wide ecological tolerance.

Because this exchange of species now happens globally, it can be seen as a hazard to global biodiversity. There are many sensitive ecosystems such as islands, for which this is a real danger, threatening the character of these unique living communities. This would cause a loss of the identity of an entire ecosystem[10]. However, in Germany the situation is slightly different. Because of the Ice Age all surviving and still existing species are very resistant and competitive[12].

2.2 The suitability of the German waterways for aquatic invasive alien species (AIAS)

In the last 100 years the number of AIAS in German water bodies has risen dramatically[71]. There are different causes for this trend. During and after the industrial revolution, untreated wastewaters were discharged into rivers and streams. River water was used as cooling water for power plants, altering the temperature range of the local aquatic environment. Additionally, rivers were canalised for irrigation and transport without consideration of the habitat losses. What remained were water ways without ecological variance, hence very low in species richness.

Since the seventies, communal and industrial wastewaters have been subjected to a higher standard of treatment. This has resulted in a steady improvement of water quality in rivers, streams and lakes. Accordingly, more and more species which were previously found only in small surviving populations have resettled in the improved waters. Nevertheless, many ecotopes have been left vacant, and because of the rising international traffic, many new species have been introduced. Additionally, because of the Ice Age there is a lack of species, especially crustacean[12], causing more open ecological niches. And it is obvious, that the proportion of crustacean AIAS is high (see Table 1).

In 1971 the proportion of invasive macrozoobenthic species in the Rhine was 38 % with some of those species showing signs of rapid expansion. But by 1980 they decreased to 11 % and the danger of rapid expansion had declined, too[72].

The European river system is a network with the main rivers being the Rhone, the Rhine, the Elbe and the Oder in north-south orientation, and the Danube, the Bug, the Pripjet, the Mosel and the Seine in east-west orientation (Fig. 1). There are so many canals connecting these rivers that boat travel is possible almost everywhere in central Europe. All these waterways are potential routes for the spread of AIAS. In 1992 the Rhine-Main-Danube Canal opened, and this shortcut from East to North was used by many pontocaspian species (see Table 1) to invade from the Danube-into the Rhine-system[73].

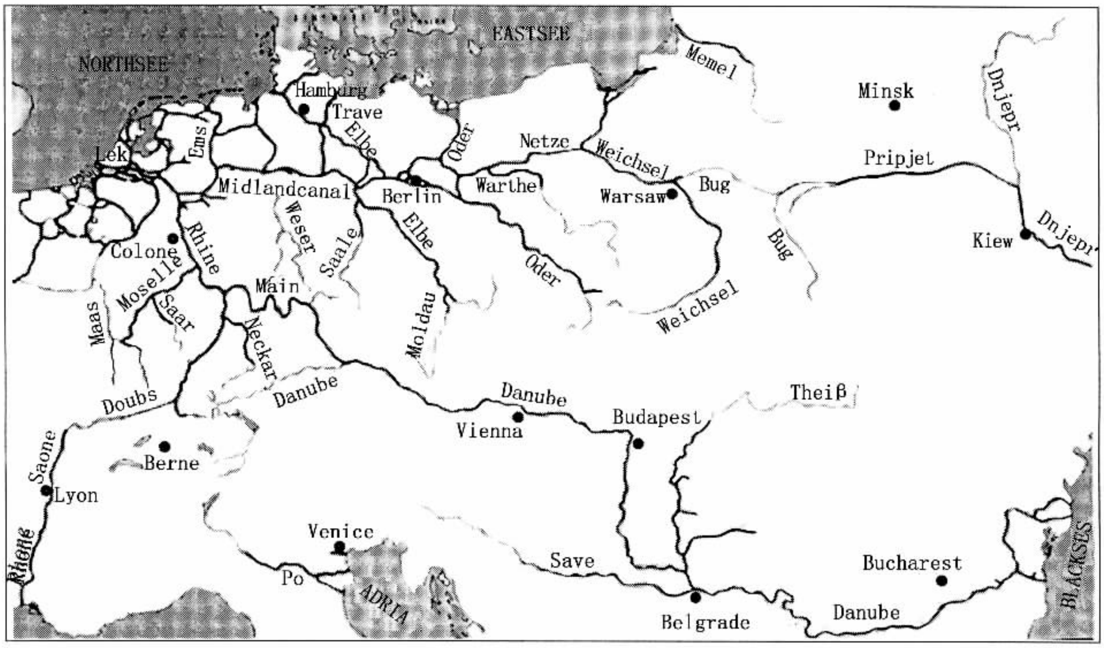

Fig.1 European main river system and water ways

To analyse the possible causes which facilitate the dispersal of AIAS, we investigated 10 tributaries in the Rhine-area between Koblenz and the border of the Netherlands in 1996. Our hypotheses were that human impacts in particular can facilitate the dispersal of AIAS. Therefore, the tributaries were chosen with respect to navigability, water quality, salinity and temperature pattern. Those factors are an indication of the degree of human impact. The Rhine area was chosen because the Rhine is one of the biggest rivers in central Europe with the highest traffic rate. The Rhine is connected to the North Sea and other river systems in east and west via canals. Also a large number of industries are situated along its banks, using its water for cooling and discharging waste water into it[74]. The fauna of the Rhine is one of the best investigated in European rivers and the arrival of AIAS has been documented for decades.

All tributaries have a direct and natural connection to the Rhine. The invertebrates were sampled within a 15 km section up from the tributary mouth. We used the "kicking technique"[75] with a meshsize of 0.5 mm and 20 cm diameter net. Samples were preserved in 70% ethanol in the field and returned to the laboratory where invertebrates were separated from organic matter and inorganic material by elutriation. Any remaining, relatively heavy invertebrates (e.g. molluscs and caddisflies) were removed by hand from the elutriation trays. All aquatic invertebrates were sorted and identified to the lowest taxonomic level possible (species in most cases) under a stereomicroscope (Stemi SV 8, Zeiss, Jena, Germany; magnification 6 – 80 ×). Chironomidae were identified to subfamily and Oligochaeta to class. Table 2 shows the results of the investigation.

The tributaries are sorted by their proportion of AIAS. Tributaries that have suffered two or more incidents of human impact show a higher proportion of AIAS, than those with none (Kalflack, Wied, Ahr) or only one incident (Sieg) of human impact. Navigability and salinity seemed to be the most influential factors which facilitate the success of AIAS. The river Mosel, which has been affected by three factors of human impact (navigability, elevated salinity and low water quality), showed by far the highest proportion of AIAS (25%). All species of AIAS that were found in the various waterways during the study were also found in the Rhine. It is self-evident that the origin of all the AIAS was the Rhine. This shows that all connections in the river system are open to AIAS and that they could reach every part of every river connected with the main water ways in central Europe.

Table 2 Comparison of 10 Rhine tributaries with respect to different human impacts (marked with asterisk *)

Tributary name	Navigability	Salinity	Temp. pattern	Water quality[LAWA 1995]	Total species number	Proportion of AIAS [%]
Mosel	Yes *	Elevated *	Normal	2, 2-3 *	24	25,0 (* * *)
Lippe	No	Elevated *	Normal	2, 2-3 *	58	17,3 (* *)
Ruhr	Yes *	Normal	Normal	2, 2-3 *	36	13,8 (* *)
Lahn	Yes *	Normal	Normal	2, 2-3 *	45	13,3 (* *)
Erft	No	Normal	Elevated *	2, 2-3 *	27	11,1 (* *)
Wupper	No	Normal	Elevated *	2, 2-3 *	31	10,0 (* *)
Sieg	No	Normal	Normal	2, 2-3 *	23	8,6 (*)
Kalflack	No	Normal	Normal	2	68	5.9
Wied	No	Normal	Normal	1-2, 2	34	3,1
Ahr	No	Normal	Normal	1-2, 2	39	2,6

This result confirms the theory that human impacted environmental systems are more susceptible to AIAS than natural and stable systems. The proportion of AIAS was much higher in the sections of waterways subjected to human impact than those not affected by human impact. In Germany the best protection for the original biocoenosis is environmental protection through biotope protection and biotope conservation measures. If the living communities are not weakened because of environmental pollution or other habitat changes, they are very competitive and strong. Until today, in Germany, AIAS have not displaced any of the native species. Here, the question of the danger of AIAS to native communities must be asked in a different way. The character or the identity of native communities is in danger not because of AIAS, but because of environmental changes caused by human impact. It is a fact that almost every waterbody in Germany is affected by human impact - (see above) and consequently the native communities are weakened or even reduced in their biodiversity. Such waterbodies are open to AIAS, which often settle successfully because of their wide ecological tolerance. They occupy the vacant ecological niches, and should the environmental conditions improve, native species are unable to return. Most AIAS are well integrated in the central European waterbodies with several species being important factors in the food chain. *Dreissena polymorpha* for example, is an important food source for migrating water birds. *Corophium curvispinum* is an important food source for many fish species[10]. On the other hand, in times of outbreaks, single species can cause great economical damage. For example, in the Lake of Constance, *Dreissena polymorpha* blocked pipes of waterworks and *Eriocheir sinensis* damaged fishnets in the lower Elbe[76]. But such phenomea existed for only a few years until a biological balance returned.

3 Summary

Dodd[5] presents a conceptual ecological model, considering that exceptions exist. We can use this model to summarise the problem.

a) Most invaders fail to establish. As failed invasions are never documented, the success rate of invasions is not well-known.

b) Most successful invaders are integrated without major effects on the ecosystem or community, although some have major effects.

c) All aquatic systems can be invaded.

d) Major effects are observed most often in low-diversity systems, including island and highly disturbed habitats.

e) Top predators that invade successfully are more likely to have a strong environmental effect than successful invaders at lower trophic levels.

f) Species must have physiological and morphological characteristics that suit an environment to invade successfully.

g) Invaders are most likely to become established when native species are disturbed. Natural or anthropogenic disturbance increases susceptibility to invasion.

h) Success of invaders can depend on environmental variability.

i) Very stable systems may be susceptible to invasion, although current data do not confirm this.

j) The greater the number of invading individuals and the greater the frequency that they are introduced, the greater the probability that they will become established.

k) Species with a history of being invasive are most likely to invade other habitats.

We can conclude that understanding the ecology of ecosystems is the most essential element in understanding and managing the occurrence and impact of AIAS.

In Germany, the danger of AIAS is present all the time because of the disturbed environment and the huge amount of international traffic. The lack of species caused by human impact and the Ice Age is obvious, so that consequently AIAS have no problems to find open ecological niches and settle successfully. On the other hand, the danger that AIAS cause extinction of native central European species is to be ranked very low. Because of the Ice Ages the remaining German living communities are very competitive and stable and can survive the competition with AIAS.

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大型底栖动物入侵种 :它们是否对德国水生动物群落构成威胁？

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摘　要 :在水体中发现大型底栖动物入侵种是一种世界范围普遍的现象。人类移动的同时将物品从一个大陆带到另一个大陆,这使许多水生动物物种能够突破自然的防线侵入到其他的区域和大陆。藉由人类现代的旅行方式,在不同区域间移动的物种数量显著增加,成功入侵种的数量也随之增多。成功入侵种需要具备一些特征,如可动性,小体型,适应性强和繁殖率高等,这些均有利于物种跨区域的入侵。当然,新生活环境也必须满足可适应的标准。对一个受人类活动破坏而丧失其原有物种的水环境来说,它对新物种入侵的抵抗力会很弱甚至缺乏。德国水体受人类活动的胁迫非常严重,许多自然水体受到的破坏已无法挽回,有些甚至已经完全成为了人工环境。这些水体由相互连接着的溪流河川网络组成,这很容易使新物种的入侵范围扩大。在外来物种的入侵面前,受人类活动胁迫和直接破坏的水体,比尚保持着天然环境状况的水体更加脆弱。

关键词 :底栖动物 ;群落 ;入侵种 ;德国 ;水体

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