Aquatic alien species in Germany – Listing system and options for action

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Summary

This paper focuses on the implementation of a listing system for aquatic alien species in Germany, equivalent to the 'Black, Grey, and White List' of the European Strategy on Invasive Alien Species. Potential candidates for a German 'black list' of aquatic IAS (naturalized species and species under naturalization in German waters) are nominated.
Within this framework, options are to be set out to provide a basis for action on alien species: (a) prevention; (b) early detection; (c) risk assessment and management strategy; (d) rapid measures; (e) mitigation/control; (f) monitoring; and (g) acceptance.

Key words: invasive alien species, management, national strategy, white list, grey list, black list, warn list, action list, management list

1. Introduction

The introduction of species into habitats outside their native ranges is closely linked to the increasing globalization of trade and travelling (Mooney & Hobbs 2000). These alien species represent a growing problem due to their unexpected and unwanted impacts on the native biodiversity as well as on the economy and human health. And global warming favours the establishment of more cosmopolitan species across wider geographic areas.

For decades the worldwide implications of alien species have been identified by non-governmental and governmental organizations, as well as emphasized in numerous international conventions and other legally binding and non-binding instruments (SCBD 2001, Shine 2006). Therefore, the implementation of sound strategies to deal with biological invasions is a global conservation priority.

On the basis of the Convention on Biological Diversity (CBD 1992), the European Strategy on IAS was finalized in 2003 (Council of Europe 2003), to combine existing regulations established under the Bern Convention in 1979 and its subsequent agreements, and to offer the signatory states possibilities to deal with alien species. However, despite the remarkable efforts to provide instruments for the best management of alien species, implementation is taking a hesitant course at present. In some cases, the reasons for gaps between available instruments and their implementation can be found in a lack of national strategies in some countries, or limited public awareness and unclear decisions (Miller et al. 2006). As a consequence, the rate of alien

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introductions is still increasing continuously no change is as yet visible (Sandlund et al. 1999, Nentwig et al. 2005, Nentwig 2007).

Germany has been known for a long time as a recipient area for many alien species from all over the world. In accordance with the CBD's guiding principles, Germany has recently been preparing a national strategy on IAS (Hubo et al. 2007). Most of the alien species currently found in Germany are causing no, or only minor, impacts, but a few of them have severe ecological, economic or health consequences. The legal and organisational implementation of the strategy will therefore focus on the group of problematic and potentially problematic species. Especially aquatic habitats are particularly prone to biological invasions. In German waters the invasion rate in the past 20 years was approximately three newly established alien species per year (AeT umweltplanung 2008). Many of the introduced species are abundant and several can be regarded as invasive (Nehring 2005, Gollasch & Nehring 2006). However, aliens in German waters are still perceived only at a descriptive level. The aim of the present paper is to build awareness, reduce uncertainties and designate potential management instruments and strategies for aquatic alien species. The paper focuses on the implementation of a listing system in Germany as part of a national strategy on IAS, equivalent to the 'Black, Grey, and White List' of the European Strategy (Council of Europe 2003), and on options in general to provide a basis for action on alien species.

2. Alien species in German waters

About 126 alien species are established in German waters (AeT umweltplanung 2008). The majority are benthic macroinvertebrates (72 species), primarily crustaceans, molluscs, polychaetes and hydroids. Introduced macrophytes comprise 20 taxa, mostly macroalgae and waterplants. Among vertebrates, fishes are the dominant group. Intentional fish introductions were predominantly caused by sport angling. About 70 'alien' fish species have to date been recorded in German waters (Geiter et al. 2002) with, however, only twelve species considered established.

Many alien species are at least locally abundant and every second alien species has spread successfully across a larger area. Between the three German aquatic ecoregions (inland waters, North Sea coast and Baltic Sea coast) there are major natural hydrographical and topographical differences, which is also reflected by the occurrence of alien species. At least 82 alien species are regarded as established in inland waters. On the North Sea coast, along with the Wadden Sea and several estuaries, a total of 50 established alien species are known. Only 28 alien species have become established on the German Baltic coast to date. Several alien species are established in inland and coastal waters because they can adapt to a wide range of salinities including freshwater (e.g. the Caspian zebra mussel *Dreissena polymorpha* and the Chinese mitten crab *Eriocheir sinensis*).

Shipping canals, ballast water, ship hull fouling, aquaculture, stocking and ornamental trade are the main pathways that have been identified as significant for the introduction of alien species into German aquatic habitats (Nehring 2005). 80% of the established alien species were introduced unintentionally. In Germany, the invasion rate has been increasing in all waters during the last ten years, with the highest increase recorded for inland waters (Gollasch & Nehring 2006).

In spite of the insufficient scientific analyses, approximately 20 % of the established aquatic alien species in Germany have clearly negative effects on the natural balance (Table 1, Fig. 1), which means that they endanger biological diversity on one or more levels (ecosystems, habitats, species or genes). In contrast to definitions used in science (e.g. Kowarik 2003), but in accordance with nature conservation definitions (e.g. CBD 1992, 2000), these species are seen as invasive species and therefore demand appropriate measures. 'Strict' definitions which clearly relate to ecological damage are of special importance for nature protection, as they help to separate damage relevant to nature from economic, health or other damage, which may be seen as a sphere of activity for other relevant stakeholders (Klingenstein & Diwani 2005). It should also be clarified that the measures applied in these areas, for example antibiotic, pesticide, hormone, or drug applications in aquaculture to protect cultivated fishes from invasive parasites and pathogens, cannot be considered conservation measures. A simple classification, modified after Jansson (1994), can be used to document different ecological impacts of alien

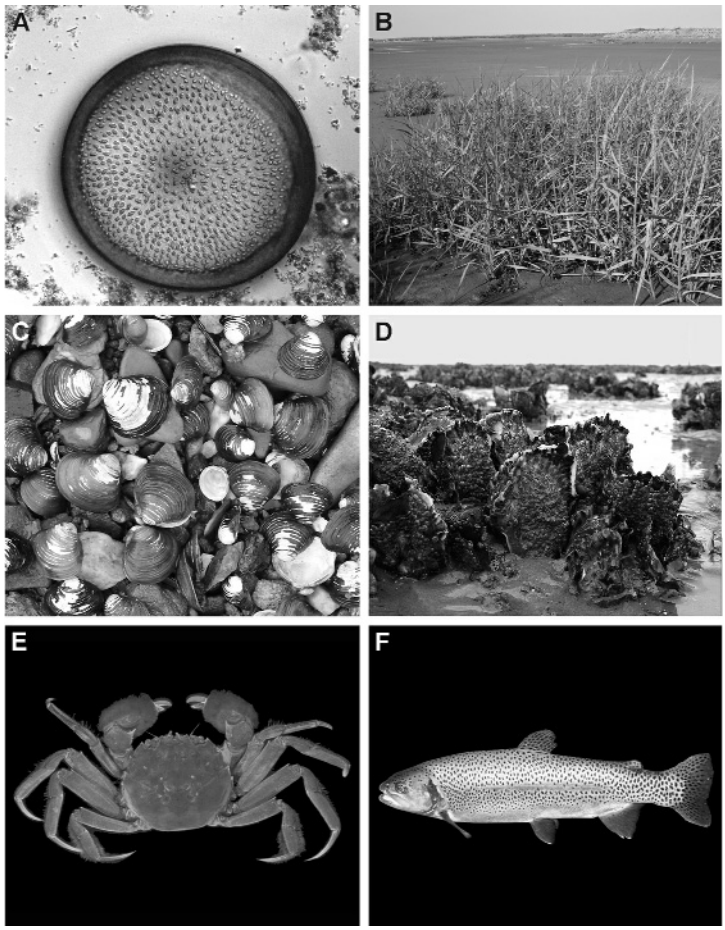

Fig. 1: Invasive alien species in German waters. A) The Indo-Pacific diatom *Coscinodiscus wailesii*, North and Baltic Sea coast. B) The common cordgrass *Spartina anglica*, North Sea coast. C) The Asian clam *Corbicula fluminea*, inland water. D) The Pacific oyster *Crassostrea gigas*, North Sea coast. E) The Chinese mitten crab *Eriocheir sinensis*, inland water and North and Baltic Sea coast. F) The Rainbow trout *Oncorhynchus mykiss*, inland water. Photos are not to scale.

Table 1: Candidates for a German 'black list' of aquatic invasive alien species which cause ecological harm (data according to AeT umweltplanung 2008, Wolter pers. comm.).

Taxon	Vector	Distribution		
		Inland water	North Sea coast	Baltic Sea coast
Species under naturalization				
Fish				
Acipenser baeri – Siberian sturgeon	stocking	X		
Ctenopharyngodon idellus – Gras carp	stocking	X		
Reptile				
Trachemys scripta elegans – Red-eared Terrapin	ornamental trade	X		
Naturalized species				
Phytoplankton				
Coscinodiscus wailesii – Indo-Pacific diatom	aquaculture		X	X
Fibrocapsa japonica – Pacific flagellate	ocean shipping		X	
Macrophytes				
Crassula helmsii – Australian swamp stonecrop	ornamental trade	X		
Elodea canadensis – Canadian waterweed	ornamental trade	X		
Elodea nuttallii – Nuttall's pondweed	ornamental trade	X		
Hydrocotyle ranunculoides – Floating pennywort	ornamental trade	X		
Sargassum muticum – Japanese weed	aquaculture		X	
Spartina anglica – Common cord-grass	planting		X	
Macrozoobenthos				
Corbicula fluminalis – Asian clam	ocean shipping	X	X	
Corbicula fluminea – Asian clam	ocean shipping	X		
Crassostrea gigas – Pacific oyster	aquaculture		X	
Dreissena polymorpha – Zebra mussel	shipping canal	X	X	X
Ensis americanus – American jack knife clam	ocean shipping		X	X
Marenzelleria neglecta – Polychaete	ocean shipping		X	X
Marenzelleria viridis – Polychaete	ocean shipping		X	X
Chelicorophium curvispinum – Ponto-Caspian amphipod	shipping canal	X	X	X
Dikerogammarus villosus – Ponto-Caspian amphipod	shipping canal	X		
Eriocheir sinensis – Chinese mitten crab	ocean shipping	X	X	X
Orconectes immunis – Calico crayfish	ornamental trade	X		
Orconectes limosus – Spiny-cheeked crayfish	stocking	X		
Pacifastacus leniusculus – Signal crayfish	stocking	X		
Procambarus clarkii – Red swamp crayfish	ornamental trade	X		
Fish				
Lepomis gibbosus – Pumpkinseed	ornamental trade	X		
Neogobius melanostomus – Round goby	shipping canal	X		X
Oncorhynchus mykiss – Rainbow trout	stocking	X		
Pseudorasbora parva – Stone moroko	stocking	X		
Salvelinus fontinalis – Brook trout	stocking	X		
Amphibian				
Rana catesbeiana – American bullfrog	ornamental trade	X		
Parasites				
Anguillicola crassus – Eel swimmbladder nematode	stocking	X	X	X
Aphanomyces astaci – Crayfish plague	stocking	X		

species on German waters in general, *viz*:

- Disruption of existing interactions between species or food web links (e.g. predators, prey, grazers, and competition) (e.g. *Crassostrea gigas, Dikerogammarus villosus, Dreissena polymorpha, Rana catesbeiana*);
- Hybridisation with native and other alien species, resulting in changes of biological and genetic diversity (candidates in German waters: *Acipenser* spp., *Crassostrea gigas, Spartina anglica*);
- Introduction of parasites and disease agents. The introduced species may function as a host for pathogens or parasites which affect indigenous species (e.g. *Anguillicola crassus, Orconectes limosus*);
- Habitat modification (e.g. *Chelicorophium curvispinum, Crassostrea gigas, Sargassum muticum*).

These alterations may be widespread or regional in particularly valuable habitats, which are usually protected habitats. Such 'ecological costs' are usually difficult or impossible to quantify (Reinhardt et al. 2003).

Most intentional introductions into aquatic environments aim to achieve some positive economic or socio-economic effects, often by improving angling opportunities or water quality, etc. In some cases the desired positive effect is realised whereas in others, the introduction has serious negative economic effects, often associated with negative consequences for the environment or biodiversity (Weidema 2000). The documentation of economic impacts from introduced species in German waters is still insufficient to determine the precise extent. Numerous economic sectors may be negatively affected by aquatic alien species, *viz*:

- Damage to waterways, watercourses and hydraulic structures (e.g. *Dreissena polymorpha, Teredo navalis*);
- impact on species used in fisheries and aquaculture, resulting in a decrease of outputs (e.g. *Anguillicola crassus, Eriocheir sinensis, Crassostrea gigas*);
- Impact on resource users may result in harmful consequences for human health and well-being, recreation, and socio-economics (e.g. *Crassostrea gigas, Elodea canadensis, Spartina anglica*).

In the last decades several aquatic IAS eradication and control programmes were carried out in Germany, but most of them failed. In the early 1960s an experiment was initiated to eradicate *Spartina anglica* locally in the Wadden Sea of Schleswig-Holstein (Nehring & Hesse in press). Several herbicides were tested but the results showed that single treatments were ineffective in the long run. Attempts to extirpate invasive American crayfish at several locations by means of fishing weirs have proved ineffective, primarily because this procedure targets only large adults; the remaining juveniles then take over the previously occupied territories (Frutiger et al. 1999). For several years the invasive bullfrog *Rana catesbeiana* has reproduced successfully in natural ponds and lakes near Karlsruhe. From 2001 to 2004 eradication measures were carried out each year, and more than 15,000 tadpoles, about 8,000 juveniles and 196 adults were killed. The success of eradication measures is still being discussed but up to now, the spread of the population could be prevented (Waitzmann 2005). In the past, aggregations of zebra mussel *Dreissena polymorpha* obstructed water intakes. Water utilities in Germany have adapted to this zebra mussel problem, and since the 1970s, water intake pipes have been sited at depths where the occurrence of zebra mussels is much lower (Reinhardt et al. 2003).

3. Listing system and options for action

In Germany, both the public and decision-makers often have a limited understanding of the threats posed by aquatic IAS. However, the ways in which alien species affect native species and ecosystems are numerous and usually irreversible. Impacts are sometimes massive but often subtle. Therefore the management response to problems posed by IAS should become a central concern.

3.1 Listing system

The listing of species is an effective tool for dealing with IAS issues. The European Strategy on IAS (Council of Europe 2003) recommends that all aliens be sorted into three categories: (1) a white list of species for those which are harmless and might even be of use or benefit; (2) a grey list of species whose category is unclear; (3) a black list of species which cause serious harm. However, species lists and decision-making need to be based on transparent scientific criteria that are periodically reviewed.

Regional 'black lists' of invasive species known to be harmful are a useful tool and can be used to help preventing the introduction of damaging species into new areas and to allow the prioritisation of eradication actions (Branquart 2006, Council of Europe 2003). A system of 'black and grey/watch lists' has been developed recently e.g. in Switzerland with a focus on terrestrial neophytes (Weber et al. 2005), in Romania with a focus on terrestrial and freshwater neophytes (Anastasiu & Negrean 2005), in Belgium with a focus on terrestrial and freshwater species (Branquart 2006) and in Norway with a focus on all taxonomic groups and habitats (Gederaas et al. 2007). In Germany a criteria-based listing system for both alien plants and animals in aquatic and terrestrial habitats is now being developed (Nehring et al. in prep.).

Species listing is an approach for comprehensive IAS treatment which will lead to better IAS management. A listing system for alien species could include the following components:

a) Black list

On a 'black list' all alien species are listed whose risk analysis has shown that they are invasive. Further proliferation and/or long-lasting harmful impacts should be prevented by ongoing mitigation/control of black listed species. The commercialisation and the intentional release of black listed species should be prohibited. Special kinds of 'black lists' are the 'warn list', the 'action list' and the 'management list'.

On the 'warn list' all those species are listed which are not yet naturalised in Germany and black listed in one or more other regions or countries. The 'warn list' is a helpful administrative instrument within the scope of authorisation because of its synoptic approach; the competent authorities thus obtain a complete overview of species black listed elsewhere without delay. However, no 'warn list' of aquatic species in Europe has been available up to now; moreover, it is not clarified which kind of institution should keep and maintain such a list.

As prevention may fail, a newly introduced alien species should get special attention because it is - or could become - invasive, especially if it is black or warn listed elsewhere. Directly after first detecting an alien species, the competent authorities have to assess the current situation by determining the risk potential of the target alien species as well as the native ecosystems, habitats or species threatened.

If established species and species under naturalization are declared as invasive, the spread of these species must be prevented. Species that are at the initial stage of invasion, in that they have only formed few and small isolated populations, should be placed on the 'action list' if at least one efficient eradication method is available. Action listed species have a high priority and should be eradicated by rapid measures, if possible.

If eradication is not practical because no efficient methods are available or the targeted invasive species has formed too many populations, it should be placed on the 'management list'. For the species on this list, active control measures should be undertaken to reduce impacts and further expansion.

On the basis of a first assessment and considering scientific literature and findings, candidates for a German 'black list' of aquatic IAS (naturalized species and species under naturalization in German waters) are nominated in Table 1. They have been selected because of the known severity of their impact and because it is likely that information will usually be available on the water bodies in which they occur. For a definite 'black list', however, all known alien species in German waters should be evaluated by a risk assessment.

However, the urgent implementation of an official black list in Germany is restricted by difficulties with legal issues. Species that are black listed need to be removed from the current patchwork of local, regional, national and international regulatory jurisdictions (e.g. hunting and fisheries regulations), and placed under a unified, coherent management authority. More than 50% of the invasive species in German waters were introduced intentionally by man, e.g. for ornamental or stocking purposes (Table 1). This means that their ecological (and economic) impacts could have been avoided through awareness and legislation based on risk assessment analysis.

b) Grey list

On a 'grey list' all those alien species are listed whose probability of becoming invasive is uncertain because of data deficiencies. Apart from taking into account the results from monitoring, (further) reviews / analyses will be required before a decision about the invasiveness of these species can be made. The commercialisation and intentional release of grey listed species is not authorised at this stage.

c) White list

On a 'white list' all those alien species are listed whose risk analysis has shown that they pose a 'low' environmental risk. Their occurrence should be accepted. Authorisation for commercialisation and intentional introduction has been granted.

In Germany a lot of aquatic alien species have become established which are not known to have an invasive character (Gollasch & Nehring 2006; AeT umweltplanung 2008). In the context of a listing system these species could be placed on a 'white list'. However, 'white lists' should be developed by competent authorities at a national or sub-national level, and – as a precautionary measure – all species included in them should have undergone a risk assessment, which should be reviewed periodically. An important issue is if – or after how many years after arrival in a new region – a taxon can be declared to be 'safe' (non-invasive), bearing in mind that lag-phases of many decades are not unusual. Therefore the purpose of the white lists is to provide scientific information on all alien species and their potential invasiveness, so that decisions about listing them can be

made on the basis of stringent criteria in a thorough, consistent, logical and transparent way. As long as such risk assessment for a specific species is not available, this species should not be placed on any 'white list'.

The introduction of specimens of white-listed species may be authorised without restriction or under certain conditions. But care should be taken to avoid the impression that uncontrolled releases of white-listed species are encouraged. The use of 'white lists' should not prevent us from giving preference to native species of local provenance where appropriate.

The listing system is comprehensive in that all species are recorded on one list or another, and it should be dynamic, i.e. it should permit shifting species from one list to the other. For example, once a species has been authorised for entry into a country after a risk assessment, and importations have occurred for a long period, the risks have to be reassessed at appropriate intervals since the genetic composition of the introduced population or the environment may change (e.g. degree of eutrophication, hydraulic engineering, climate change) and cause unexpected harmful reactions by the species, or new scientific information about the species may become available.

3.2 Options for action

Options for action are recommended in order to deal with the issue of aquatic alien species in an appropriate and comprehensible way. The assignment of an alien species to one of these options is based on its listing in the listing system. The CBD Guiding Principles on IAS (CBD 2000) set out a 'three-stage hierarchical approach' as the basis for action on invasive alien species: prevention, early detection & rapid measures and mitigation (of impacts).

The overall strategy for alien species in German waters is summarized in a flow diagram in Fig. 2. It comprises two main components: dealing with the problem of alien species already present in German waters, and the prevention of further introductions including the response if prevention should fail. Depending on the alien species and its actual status, management efforts are targeted at one or several of the seven following categories. In general, (a) preventive measures such as building awareness and appropriate regulations can prevent future introductions. If a new alien species has already been introduced, (b) early detection is crucial to determining its status. (c) Risk assessment and management strategy, (d) rapid measures, (e) mitigation of impacts/control, (f) monitoring of occurrence, impacts and spread and (g) acceptance are applicable to all alien species. Monitoring has a central role, providing the basis for a decision on acceptance or control and evaluating the success of measures.

a) Prevention

It is a well-known fact that the eradication of an introduced species, once it has established in the aquatic environment, will be very difficult (and expensive), or even impossible. Therefore, the prevention of introductions (at best at source) is the most effective and least costly management strategy. Moreover, prevention is the only option where different measures for intended and unintended introductions have to be applied.

An important example of preventing unintended introductions is the ballast water convention adopted by IMO member States in 2004 (IMO 2004). It will enter into force 12 months after its ratification by 30 States, representing 35 per

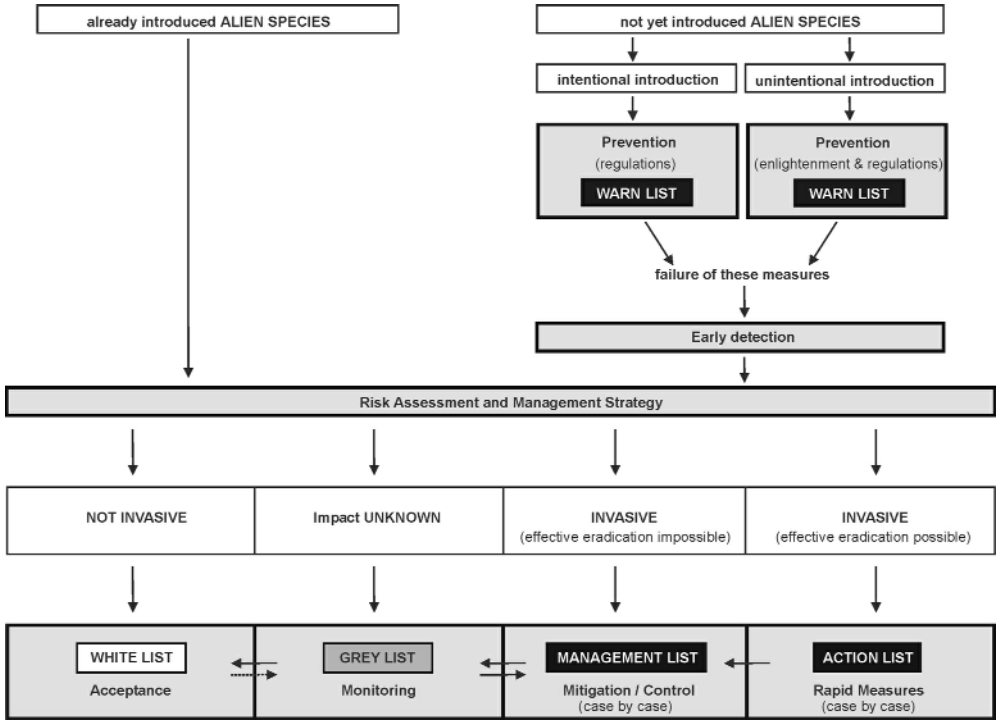

Fig. 2: Listing system (Black list – warn list, action list, management list; Grey list; White list) and options for action (Prevention; Early detection; Risk assessment and management strategy; Rapid measures; Mitigation/Control; Monitoring; Acceptance) for introductions of aquatic alien species (further explanation see text).

cent of the world's merchant shipping tonnage. However, the convention does not prevent all unintended introductions associated with shipping since it only covers ballast water management. But solutions with environmentally acceptable methods for the control of hull fouling are also urgently needed now that TBT-based antifoulants have been banned in many countries (Nehring 2001). And up to now there have been no activities focusing on shipping canals, although this pathway is of highest relevance for alien invasions in aquatic ecosystems, especially in Germany (Nehring 2005; Galil et al. 2007).

As far as intended introductions are concerned, many releases of alien organisms have been undertaken without taking into account the possibility of detrimental effects. Some organizations have developed guidelines and codes of practice (e.g. the ICES Code of Practice on introductions and transfer of marine organisms, the EIFAC Code of Practice and Manual of Procedures for consideration of introductions and transfers of marine and freshwater organisms). These instruments should assist key authorities (e.g. government agencies, regional authorities, professional associations for fishing) in determining whether an introduction is justified, and advise them on what to do after an introduction has been approved. However – because these are voluntary rules – they have lacked efficiency up to now.

As a legal instrument, the European Commission (2006) proposed a council regulation concerning the use of alien and locally absent species in the European aquaculture industry. This is a first step in the right direction. But due to the high potential for dispersal of introduced aquatic species and the high probability of subsequent dispersal along coasts and shipping ways, adequate precautionary measures are needed (which are not restricted to members of the European community) beyond an international management plan. A decision not to introduce a specific species for culturing would merely postpone the potential invasion unless the same decision were to be taken for neighbouring water bodies outside the European community (e.g. aquaculture activities at the Russian Baltic Sea coast).

In Germany, the precautionary principle is laid down in the current legal framework (the main instrument being the Federal Nature Conservation Act) (Holljesiefken 2007). As an environmental goal the release of alien species must be minimized. Besides, the national potential for the prevention or control of the import of organisms should be co-ordinated. In a research project (Hubo et al. 2007) the administrative and legal framework for all sectors involved in the introduction and management of IAS were analyzed. It provided the basis for a national strategy and the results were used in recent efforts to improve IAS regulations in the Federal Nature Conservation Act. The amended Federal Nature Conservation Act is expected for 2009.

It is clear that laws should be enforced and that particularly lax practices should be stopped. In this context an important step towards prevention is to identify those alien species that may become invasive and therefore require special attention. These should be put on a 'warn list' as a simple but effective prevention measure because it thus becomes clear for which species there should be no uncontrolled releases (see Chapter 3.1).

An important additional aspect of preventing unintended and intended introductions is the raising of awareness/ enlightenment of politicians, management authorities, companies, scientists as well as the public about alien species, their risks and the possibilities to prevent further introductions. Purposeful campaigns could be relatively effective by informing about the hazards of bringing alien plant species back home from vacation, or releasing (alien) pets or aquaria into the wild. In addition to presentations in the scientific world and for the public public, web-based information platforms offer a great chance to enhance awareness of the alien problem continuously (e.g. the German web-sites www.neobiota. info, www.neophyten.de, www.neozoa.de).

b) Early detection

The development of an effective early detection system is necessary to detect and to determine the status of newly occurring alien species in the wild. This is essential for taking rapid measures at the earliest possible stage of establishment or spread. IAS which are listed on 'black lists' elsewhere/in other regions/countries or on the 'warn list' should receive special attention (see Chapter 3.1). However, in aquatic environments, new species are much more difficult to detect than in terrestrial habitats. Therefore an aquatic early detection system should be well thought through and developed, by taking account of existing capacities and established monitoring programmes. In particular, alien species of all relevant groups should be targeted at regular intervals at key sites in German waters, espe-

cially in areas near high-risk entry points such as large estuaries (e.g. Elbe, Weser; see Nehring 2006), ports (e.g. Bremerhaven, Duisburg, Hamburg, and in the near future Wilhelmshaven after the opening of the Jade-Weser-Port; see Gollasch & Leppäkoski 2001), shipping canals (e.g. Main-Danube-Canal; see Nehring 2005), and aquaculture plots (e.g. Pacific oyster farm near the island of Sylt; see Wolff & Reise 2002). And apart from this, an important component of an aquatic early detection system should be the integration of fishermen because many first discoveries of aquatic alien species are made by them (Nehring et al. 2008).

In addition, staff responsible for biological aquatic investigations needs to be trained. Training must include the acquisition of a comprehensive taxonomic knowledge about the different relevant groups of aquatic organisms, the use of databases and identification services, and surveying methods. It is in the nature of an alien species which is introduced into a new country that it is not usually listed in the national field guides.

c) Risk assessment and management strategy

Various methods of performing risk analyses on alien species have been employed (e.g. Morse et al. 2004; Copp et al. 2005; Hewitt et al. 2006), but there is still no international standardised methodology. The risk assessment process usually begins with the identification of target species and pathways. Alien species need to be arranged on a priority list that takes into consideration the extent of the area infested by the species, the rate of spread, the environmental and economic impact of the species, the ecological value of the habitats invaded and the difficulty of eradication or control. The likelihood of successful introduction is assessed through reviews of scientific literature as well as by expert opinion and qualitative/quantitative analysis. The result is a ranking of the relative risk according to the environmental hazard (e.g. low, moderate, high, unknown), naturalisation level (e.g. low, high) and eradication potential (e.g. low, high), if this is practicable and possible.

On the basis of this assessment, four main management strategies for dealing with alien species already – or newly – introduced are feasible: (d) rapid measures, (e) mitigation/control, (f) monitoring, or (g) acceptance.

d) Rapid measures

Once an alien species becomes established within a location in an aquatic system, it poses a threat to an entire region due to its rapid dispersal via rivers, shipping canals and coastal water currents (Nehring 2005). Therefore time is limited during which rapid measures are a practicable option. Especially for newly introduced IAS eradication is the most coherent solution in terms of biodiversity conservation. However, a basic requirement is the availability of at least one efficient eradication method (action listed species) (see Chapter 3.1).

If rapid measures are not initiated or do not result in species eradication, the further establishment of the species in the immediate environs can be very costly. For example, in the 1990s individuals of the invasive bullfrog (*Rana catesbeiana*) were released in a pond near Karlsruhe, Germany. In the following years the bullfrog established several free-living populations in five ponds and lakes which are located next to each other. First eradication measures were not conducted until 2001. Up

to 2004 the five water bodies were electronically fished and pumped out twice each year. The costs were estimated by Reinhardt et al. (2003) to be approx. 53,000 per pond per year, all in all about one million Euro. One single action promptly taken – directly after the detection of individuals in the 1990s – would have reduced the costs drastically.

For aquatic habitats no rapid measures on IAS have been carried out in Germany to date. However, it is conceivable that with the establishment of an early warning system, newly introduced invasive species can be eradicated more promptly and successfully.

e) Mitigation/Control

If an alien species is defined as invasive after a risk assessment and if rapid measures fail or are not practicable, the competent authorities may be able to prevent further proliferation and/or minimize harmful impacts by taking mitigation/control measures (management of listed species) (see Chapter 3.1). Although it is almost hopeless to eradicate widespread IAS, especially in the aquatic environment, the negative impact of these species should be reduced to an acceptable level by controlling their density and abundance. As mitigation measures, control methods should also be selected, while taking into consideration the conservation value of the habitat as well as the efficiency, selectivity and the undesired effects these methods may cause. This should be in accordance with legal codes and regulations.

In general, every measure should be based on a case-by-case decision depending on the local conditions. In order to evaluate the success or failure of a management programme, it is necessary to monitor and, if necessary, adapt the efforts undertaken.

f) Monitoring

As the potential invasiveness of aquatic alien species is uncertain, they should be placed on a 'grey list' for the time being (see Chapter 3.1). As regards these species, monitoring is of special relevance to obtain information about their invasibility, spreading and establishment, or about the efficiency of measures.

Although the federal nature conservation law specifies an obligation of environmental observation, a monitoring scheme for aquatic alien species is still missing. Such schemes should be based on existing data and instruments (e.g. Bund-Länder Messprogramm) as well as the development of new mechanisms such as expert consultation and early detection systems. The European Water Framework Directive (European Parliament and Council 2000), aiming to restore good ecological quality in all inland, transitional and coastal water bodies, could be a potentially powerful legislative measure to deal with all kinds of environmental pressures and impacts. The Directive requires that an integrated monitoring programme be established within each river basin district including coastal waters. In many cases, these monitoring programmes will be extensions or modifications of existing programmes and will enable collections of the physical, chemical and biological data necessary to assess the status of water bodies. Alien species should be a key parameter in the monitoring design.

g) Acceptance

Many aquatic alien species which are already introduced and established are innocuous and have no relevant ecological or economic effects (Gollasch & Nehring 2006; AeT umweltplanung 2008). These species should be accepted as

new components of our flora and fauna and should be placed on a 'white list', after a critical re-assessment of their effects (see Chapter 3.1).

4. Conclusions

Alien species may have significant negative environmental, economic and public health impacts. Alien invasions in aquatic systems are usually irreversible and should be prevented wherever possible. At present, most analyses that evaluate patterns of aquatic invasion or test specific hypotheses use data from existing literature, which is derived extremely unevenly in terms of both space and time. Thus priority shall be given to the development of strategies and action plans at national and regional level which are consistent and harmonised with the European Strategy on Invasive Alien Species. For new intentional introductions, a risk assessment procedure should be developed.

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