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To be, or not to be, a non-native freshwater fish?

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Summary

We examine the evolving concept of what constitutes a non-native (or alien) freshwater fish. In an attempt to distinguish between biogeographical and socio-political perspectives, we review the patterns in the introduction and dispersal of non-native fishes in Europe and North America, and especially the recent expansion of Ponto-Caspian gobies in Europe. We assess patterns in the development of national policy and legislation in response to the perceived threat of non-native fish introductions to native species and ecosystems. We review, and provide a glossary of, the terms and definitions associated with non-native species. Finally, we discuss perspectives as regards the future treatment of naturalized species.

Introduction

To be, or not to be, a non-native freshwater fish? That is the question. Whether t'is nobler in the mind that an alien fish be of commercial value, or to be one of conservation interest and by being one, avoid the slings and arrows of outrageous contempt?[1] And what of this question, the essence of being native or non-native? T'is simply biogeographical or justly or unjustly supplanted by legal definition? And should they be non-native but of commercial interest? Does this render their impact less severe or merely more acceptable? And what of endangered species, be they exotic to our waters but native and threatened elsewhere? Should these be welcomed with open arms or be the target of equal contempt? And how shall we treat those species for which the origin remains clouded by uncertainty?

A multitude of questions and debates has arisen as a consequence of the rapid rise in fish introductions and translocations. Whether intentional or unintentional, introductions of exotic freshwater fish species have subsequently been viewed either as advantageous, of neutral value, or highly 'undesirable' and even as ecological abnormalities. Lodge (1993) reminds us, however, that biological invasions are common-place in nature, resulting from climatic, geotectonic or other natural events. According to the so-called 'tens rule' (Williamson, 1996), only 10% of introductions end with establishment, and only 10% of cases of successful naturalization may be regarded as 'pests' and 'weeds'. Nonetheless, there is increased concern over the potential impacts (adverse or beneficial) of introduced species on native species, ecosystems, local and national economies, and societies, through either direct (Manchester and Bullock, 2000) or indirect effects, e.g. parasites or pathogens (e.g. Kennedy, 1975). Indeed, concern is warranted given that naturalization of marine and freshwater invaders 'may be irreversible [or unpredictable, ICES, 2004], and it is arguable whether any intentional introductions are acceptable' (p. 95, Smith et al., 1999).

Fish are a prominent feature in most national economies, but the risk management measures (e.g. quarantine controls) are generally less stringent for fish (see Copp et al., 2005a) than for terrestrial plants, plant pests [e.g. the European Plant Protection Organisation (EPPO)] and animals (especially mammals). Indeed, the problems associated with aquatic non-native species, especially those associated with the aquacultural industry, are only now being addressed in draft EU legislation (Proposal for a Council Regulation – Setting Rules Governing the Use of Alien Species in Aquaculture, Council of the European Union, Brussels). The recent increase in attention given to non-native species introductions has been accompanied by an equal increase in misuse and confusion surrounding the definitions and terms associated with non-native species, which are partly because of the political rather than biogeographical assessment of 'nativeness' (e.g. Mathon, 1984; Persat and Keith, 1997).

In most, if not all, of the previous papers to examine the issue of 'nativeness', the definition and the associated socioeconomic or political dimensions have been principally derived from the field of terrestrial ecology, although definitions of some terms can be found from other sources (FAO, 1998; ICES, 2004). Taking a distinctly freshwater fish point of view,

[1]Inspired by *Hamlet, The Prince of Denmark*, Act 3, Scene 1, by William Shakespeare, first performed in 1603.

the aim of the present paper is to: (1) provide a summary (i.e. not comprehensive) review of the definitions associated with terminology used in invasion biology, with recommendations on the use of terms; (2) provide a summary review of the patterns of fish introductions and expansions affecting Europe and North America, with particular cartographic emphasis given on the recent range expansion in Europe of Ponto-Caspian gobiids because of their rapid dispersal and demonstrated detrimental impacts, where introduced outside their native range (Corkum et al., 2004); and (3) summarize the similarities and differences in legislation and policy (biogeographical vs nationalist perspectives) that have developed in response to the increased governmental recognition of risks posed by non-native fish introductions.

Definition of terms

A major impediment to governmental and non-governmental organizations, in the struggle to prevent the introduction and mitigate the establishment and impact of non-native species, is the definition of what is native and what is non-native, which of the non-natives is acceptable (i.e. desirable for social and economic reasons), and how to classify non-native species that are endangered in their native ranges (i.e. conservation or eradication). In the assessment of 'nativeness', it is important to understand biological invasion as a process of overcoming barriers (Richardson et al., 2000). The first barrier is geographic (Fig. 1). 'Introduction' *sensu lato* means the appearance of a species (eggs or older stages, propagules) in a new place because of, first, overcoming the barrier, and second, removal of the barrier. 'Introduction' *sensu stricto* means mechanical transfer by man of a species (eggs or older stages, propagules) to locations not normally achievable by that species. Accordingly, by using a criterion such as the 'mode of penetration into a recipient region', a non-native fish species can be characterized either as 'introduced' (intentional or accidental introduction to waters outside its native range) or as an 'independent invader' (species that has penetrated new water bodies and biotopes as a result of dispersal across previous barriers; Fig. 1). The causes for such dispersal can be natural or indirect human action, which result in new conditions (e.g. temperature regime, access routes) that permit the species to disperse into the new area. After introduction has occurred or after subsequent barriers (Fig. 1) have been removed, dispersal may be enhanced by mechanisms and circumstances, such as changes in physical habitat, hydrological regime, water chemistry, hydrosystem connectivity as well as ecosystem and genetic impacts.

To avoid ambiguity, the US National Aquatic Invasive Species Act of 2003, which re-authorized and amended the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990, specified that a 'non-indigenous species' refers to any species in an ecosystem that enters that ecosystem from outside the historic range of the species, whereas an 'invasive species' is defined as a non-indigenous species, the introduction of which into an ecosystem may cause harm to the economy, environment, human health, recreation, or public welfare, i.e. there is a significant risk attached to its introduction. In Canada, the closest legal definition is that defined by the United Nations Convention on Biological Diversity (see UNEP, 1994), and adopted by the Canadian government (Canadian Biodiversity Strategy, 1995), for an invasive alien: any species, sub-species or lower taxon introduced outside its normal past or present distribution; whereas an alien invasive species is defined an alien species, the establishment and spread of which threaten ecosystems, habitats or species with economic or environmental harm. In some respects, the Canadian and American legal definitions of alien species appear to be quite similar to the biological definitions of exotic or alien species given here below. However, the US and Canadian definitions emphasize the economic, human health and social consequences of exotic species rather than the ecological or environmental implications. The legal definitions do not describe what the acceptable level of harm or threat an exotic species must demonstrate before it is regarded as invasive and control action is required.

Some definitions of an invasive species (e.g. UNEP, 1994; Canadian Biodiversity Strategy, 1995) are more restrictive,

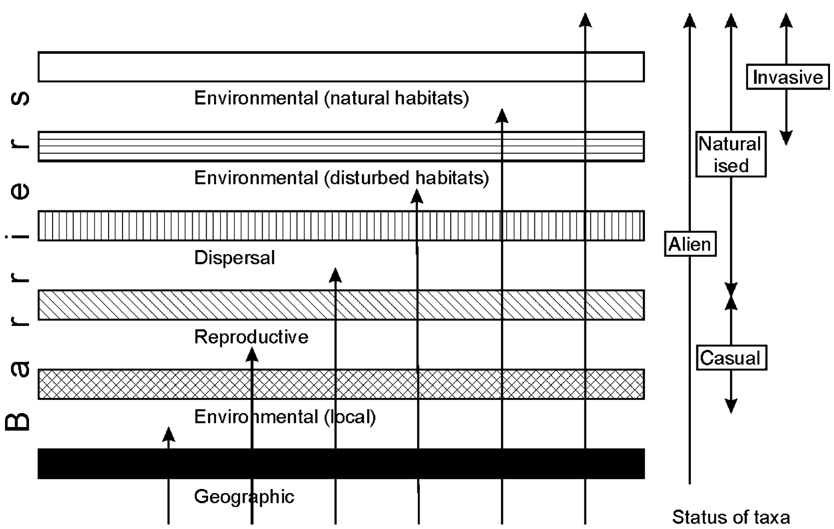

Fig. 1. A schematic representation of the major barriers that limit dispersal of introduced fishes: geographical (intercontinental and/or intracontinental); environmental (abiotic and biotic factors at the location of introduction); reproductive (inhibition or interference of spawning and/or embryonic incubation); local/regional factors; non-natural environmental (human-modified or alien-dominated hydrosystems); and natural environmental (natural and semi-natural hydrosystems). Pathways followed by taxa across barriers (from introduced to invasive) in natural hydrosystems are indicated by arrows, and these are reversible. Changes or fluctuations in climate can create new barriers (driving alien taxa to local and/or regional extinction) or offer a bridge over a barrier, permitting the taxon to survive or spread (adapted from Richardson et al., 2000)

encompassing only negative impacts (including economic) on recipient ecosystems, e.g. 'Alien invasive species – an alien [that] becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity' (Clout and Lowe, 1996; SSC Invasive Species Specialist Group, 2000). The criteria used to categorize a species as 'invasive aliens' are usually derived from subjective assessments of 'negative' consequences. These criteria are relative and anthropocentric, particularly as regards introductions to semi-natural and artificial ecosystems. In Europe, some consensus appears to have been reached in certain quarters, such as support in Manchester and Bullock (2000) of the recommended UKINC (1979), IUCN (1987), ICES (2004) and MarLIN (2005) glossaries. Richardson et al. (2000) also provided a useful glossary of definitions (for plants) that can be applied, with little modification, to freshwater fishes. A summary review of the various terms is given below.

'Acclimatized' (or 'acclimatised') – Species (or taxon) that are able to complete part or most of their life cycle in the wild in an alien environment or climate, but are unable to reproduce and sustain a population without the support of humans. The EC LIFE programme, however, specifies the support of humans as 'for food and shelter' (Scalera and Zaghi, 2004), which could be interpreted under husbandry (aquaculture) conditions. Grass carp *Ctenopharyngodon idella* is given as the example (Scalera and Zaghi, 2004), but this species was introduced in most countries specifically to eat aquatic vegetation and thus exists in the wild without human support *per se*, i.e. 'food and shelter'.

'Alien' (see 'non-native')

'Captive conditions' – Refers to controlled and isolated circumstances such as research facilities, private indoor aquaria, private garden ponds outside a river flood plain, enclosed hatcheries and fish farms, zoological gardens/parks (Bogutskaya and Naseka, 2002).

'Casual' – Refers to a taxon (species, sub-species, race or variety) that is introduced, unable to sustain its presence, despite the ability to reproduce in the novel environment (Richardson et al., 2000), without human intervention (i.e. through stocking).

'Colonization' – This is an integral part of the 'naturalization' process whereby the organisms of a founding population reproduce and the species increases in number to form a colony that is self-perpetuating (Richardson et al., 2000). Colonization is undertaken by both native and non-native species through immigration of a taxon 'into a new habitat and the founding of a new population' (Brown and Gibson, 1983, p. 559; see also MarLIN, 2005).

'Establishment' (see also 'naturalized') – refers to the process undergone by a non-native taxon (species, sub-species, race or variety), following introduction to create a self-sustaining population in the wild, beginning with successful reproduction. Establishment is thus the first phase of naturalization (see below).

'Exotic' (see 'non-native')

'Feral' – refers to an organism, or its descendants, that is domesticated, or has undergone domestication, been kept in captivity (animals) or cultivated (plants) that has escaped into the wild. A feral population is not necessarily self-sustaining (Manchester and Bullock, 2000). Difficulty may be encountered with some species to distinguish so-called feral organisms from the 'real thing', e.g. domesticated vs wild form of common carp *Cyprinus carpio* (Krupka et al., 1989).

'Foreign' (see also 'transferred' and 'introduction') – refers to a taxon (species, sub-species, race or variety) that has been moved across a national border to a country outside its native range. This only applies to an organism translocated between political states (countries).

'Indigenous' (see 'native')

'Introduced species' (see 'non-native')

'Introduction' – is the deliberate or unintentional (accidental) transfer and/or release, by direct or indirect human agency, of an organism(s) into the wild, or into locations not completely isolated from the surrounding environment, by humans in geographical areas where the taxon (species, sub-species, race or variety) is not native. This applies to translocations within and between political states (countries). This definition is consistent with that of Richardson et al. (2000), the ICES 2003 Code of Practice (referred to as a 'new introduction': the human-mediated movement of a species outside its present distribution; ICES, 2004), and the EC LIFE programme (Scalera and Zaghi, 2004). In other words, a species has overcome, through human agency, a major geographical barrier (Fig. 1). This 'biogeographical' approach to introduction contrasts the 'bio-political' approach of the FAO, which considers an introduced species to be one 'that has been moved across a national border to a country outside of its natural range' (Welcomme, 1988; FAO, 1998).

'Invasive' organisms – These are native or alien species that spread, with or without the aid of humans, in natural or semi-natural habitats, producing a significant change in composition, structure, or ecosystem processes, or cause severe economic losses to human activities (adapted from: Allard and Alouf, 1999; Scalera and Zaghi, 2004). Richardson et al. (2000) categorized such plants as 'weeds'. No equivalent term to 'weeds' exists for fish and 'pest' does not seem appropriate given that invasiveness in native taxa is most often expressed as a natural process in ecosystem succession or as a response to natural or human-generated perturbations of an ecosystem (e.g. rapid re-colonization of streams by European minnow *Phoxinus phoxinus* following reservoir-cleaning impacts; Mastrorillo and Dauba, 1999) – these are inconsistent with the concept of 'pest'.

'Invasion' – This is a collection of events and processes related to appearance and impacts on communities and ecosystems of alien species. A number of definitions exist, incorporating aspects of a species' geographic range, its sources and means (pathways) of introduction, its reproductive strategy, its dispersal rates, and its impacts on native species and ecosystems: (1) dispersal of a species into a locality that is not native to that species, and inclusion of the species into a community of species new for it; (2) all cases of penetration of living organisms into ecosystems situated beyond the limits of their initial (normally natural) range; or (3) all cases of distribution of organisms brought about by human activity (introduction) and natural shifts of species beyond the limits of their natural distribution (natural expansion of range).

'Native' or 'indigenous' – This refers to a taxon (species, sub-species, race or variety) that occurs naturally in a geographical area, with dispersal occurring independent of human intervention, whether direct or indirect, intentional or unintentional. This definition is consistent with that of Manchester and Bullock (2000) and of ICES (2004), specifically that 'a species or race thought to have occurred in a geographical area before the Neolithic can be considered to be native' (Manchester and Bullock, 2000).

'Native range' – This refers to the natural limits of a species' geographical distribution (ICES, 2004; modified after Zaitsev and Ozturk, 2001). However, range is dynamic, possessing 'the same historical notion as species' (Sinskaya, 1948), which may adapt morphologically, physiologically, or in terms of behaviour in response to environmental conditions (which probably change faster than species' ranges). In practical terms, the potential (or realizable) range of a species or race is the geographical area in which it occurred before the Neolithic (adapted from Manchester and Bullock, 2000).

'Naturalized' (or 'naturalised') – This refers to a non-native species, sub-species, race or variety that, following introduction, has established self-sustaining populations in the wild and has been present of sufficient duration to have incorporated itself within the resident community of organisms (adapted from: Allard and Alouf, 1999; Manchester and Bullock, 2000; Richardson et al., 2000). The EC LIFE definition (Scalera and Zaghi, 2004) restricts itself to 'introduced or feral species' but emphasizes that self-perpetuation is independent of humans. Thus, naturalization is successful after a taxon has achieved or overcome three barriers (or changes in status; Fig. 1): geographical displacement, local environmental barriers (resistance) to the new taxon, and regular reproduction (Richardson et al., 2000). The condition of 'widespread dispersal' could be challenged, however, with regard to fishes, which may become fully established in a number of water bodies or small river catchments within a specific (limited) part, but not all, of the new geographical range, and as such the species may not be fully 'naturalized'. Good examples of this in England are two centrarchids, pumpkinseed *Lepomis gibbosus* and largemouth bass *Micropterus salmoides*. Both species were introduced in the late 19th/early 20th century, but largemouth bass were known to have established only two populations despite repeated introductions (Lever, 1977) and these are now believed to be extirpated, whereas the pumpkinseed has established numerous pond populations in southern England (mainly the counties of East and West Sussex), with at least one confirmed population in the Somerset Levels (Villeneuve et al., 2005) and a few, as yet, unconfirmed populations elsewhere, but restricted to south of 51°N (Maitland, 2004).

'Non-indigenous' (see 'non-native')

'Non-native', 'non-indigenous', 'alien' or 'exotic' (see also 'foreign') – This refers to a species, sub-species, race or variety (including gametes, propagules or part of an organism that might survive and subsequently reproduce; Scalera and Zaghi, 2004) that does not occur naturally in a geographical area, i.e. it did not previously occur there or its dispersal into the area was mediated or facilitated directly or indirectly by humans, whether deliberately or unintentionally (Manchester and Bullock, 2000). This definition is consistent with that of Allard and Alouf (1999), which is rather concise, and more specifically with that accepted by the European Commission (EC) LIFE programme (Scalera and Zaghi, 2004) and by ICES (2004). It assumes that species that have colonized since the Neolithic, 6000 BP (i.e. about 4000 BC), are non-native. This deviates from the threshold date (5000 BP or 3000 BC) given for marine species (MarLIN, 2005), and the distinction between native and non-native may not be straightforward, relying upon estimates of the length of time a species has been resident (Manchester and Bullock, 2000).

'Re-introduction' – This is a term normally used in conservation biology to refer to the release of a species into a part of its former native range in which the species had disappeared (IUCN, 1987), i.e. 'became extinct in historical times' (MarLIN, 2005). However, in some documentation, e.g. the Czech 'Guidelines for Introduction of Fishes and Aquatic Invertebrates', the term 're-introduction' is used to refer to the repeated introduction of a non-native species in which the foregoing first introduction was not successful.

'Transferred species' (see also 'foreign') – for the purpose of the FAO database, a transferred species is one that has been moved across a national border to a country within its natural range (FAO, 1998), e.g. the movement of rainbow trout *Oncorhynchus mykiss* from the USA to Canada, where it also occurs naturally. Transfers would also include the movement of a previously introduced fish back to its native range.

'Translocation' (see also 'foreign') – is the introduction of a species, i.e. 'translocated species', from one part of a political entity (country) in which it is native to another part of the same country in which it is not native. Fuller et al. (1999) refers to such species as 'transplanted'. For example, topmouth gudgeon *Pseudorasbora parva* is native to Russia, as a political entity, being one of the less abundant fish species in the species-rich River Amur drainage basin, and existing almost without notice by local inhabitants. In the European part of Russia (over 4000 km away), however, topmouth gudgeon is a non-native species invading heavily disturbed European water bodies and dominating in smaller ponds and lakes, replacing the other cyprinids.

'Vagrant' – This refers to a taxon (species, sub-species, race or variety) that, by natural means, moves from one geographical region to another outside its usual range, or away from usual migratory routes, and that do not establish a self-sustaining popoulation in the visited region (MarLIN, 2005), e.g. sturgeon *Acipenser sturio* in British waters (Maitland, 2004).

'The wild' – This is defined as any conditions in which organisms can disperse to other sites or can breed with individuals from other populations (*sensu* UK Nature Conservancy Council, 1990). This definition would seem to imply for fish that isolated water bodies, even those essentially natural, are not 'the wild' because fish are not able to disperse from them without human or avian assistance. Indeed, the term 'the wild' was not defined during the passage of the UK Wildlife and Countryside Act. A definition of 'the wild' was sought in the Committee during the passage of the Act. Legal advice at that time was that the concept is one that everyone understands but that is difficult, if not impossible, to define satisfactorily, varying from taxon to taxon, and that should be left for the courts to decide. In absence of a court decision, audits of non-native species in the UK (e.g. 'Audit of Non-native Species in England', *English Nature*, York, Ref. VT0313), established species may include those capable of maintaining self-sustaining populations in garden ponds but not yet recorded outside such isolated conditions (e.g. fathead minnow *Pimephales promelas*).

Historical patterns of fish introductions and dispersal

East to West movements: inter-continental

There is a long history of introduction of non-native fish species within and between continents (Table 1), and this has accelerated greatly over time as methods of transportation have improved and trade barriers relaxed. However, the country with the longest history of importing non-native freshwater fishes (Germany) has the lowest number of intentional introductions. Whereas, the European country with amongst the most stringent fish importation laws at the present

Table 1
Total number of freshwater spawning fish and lamprey species by country, the number thereof that are anadromous (Anadr.,), of disputed status (Disp.), and of extirpated (Extirp.) and translocated (Translo.) native species

						Non-native			Introductions		
Country	Total	Anadr.	Disp.	Extirp.	Translo.	Total	B.N.	Legal.	Intent.	Unintent.	N.D.
Austria[1]	86	4	–	4	3	27	17	3	22	3	1
Canada	232	37	10	7	–	20	–	–	15	5	–
Czech Republic	89	8	1	9	2	30	11	10	27	3	2
England & Wales[2,3]	62	7	1	1	12?	21	14	3	13	8	–
France[4]	82	9	–	–	1?	36	32	36	35	1	–
Germany	106	16	0	13	12	18	15	12	7	8	3
Hungary[5]	81	6	2	6	0	19	13	0?	13	6	5
Italy[6]	82	7	0	4	29	39	39	8	12	23	4
Lithuania[7,8,9]	68	8	1	1?	5	20	7	1	15	3	2
Poland	81	10	1	1	1	23	11	1	13	7	2
Portugal[2]	45	6	0	1	1	12	11	9	10	2	3
Romania[10]	121	7	–	5	–	28	10	4	24	1	3
Russia	380	43	–	1?	91	31	7	5	27	1	3
Slovakia	85	0	0	5	0	28	17	7	16	6	6
Slovenia	82	1	1	–	11	16	10	3	13	3	1
Spain	69	7	1	1	8	29	25	–	21	4	–
USA[11]	908	–	–	16	316	185	68	–	92	93	–

Also given is the number of species native to part but not all of the country and have been introduced to other parts of the same country, the total number of species not native to the country (excluding all species held under captive conditions, e.g. aquaria, zoological gardens, experimental facilities), those of which have become biologically naturalized (B.N.), i.e. known to reproduce in the wild), legally naturalized (species so long established and widespread in the country that they are treated legally, and/or in practice, the same as native species), the numbers of non-native species introduced intentionally and unintentionally (as far as is known) from other countries, and those that have arrived by natural dispersal (N.D.), but facilitated indirectly by human activities.

[1]Includes four species of extirpated anadromous sturgeons, and counted as one species: resident and lake forms of *Salmo trutta* and *S. t. lacustris*, *Carassius auratus* and *C. gibelio*, all Coregonids (because of unclear taxonomy); translocations include *Salvelinus umbla* and coregonids; *Proterorhinus* is treated as native; *Oncorhynchus mykiss*, *Gasterosteus aculeatus*, *Salvelinus fontinalis* are legally naturalized; three *Neogobius* species unintentional (believed by ballast water), and *Pseudorasbora parva* by natural dispersal.

[2]Includes sturgeon *Acipenser sturio*: in the UK, it occurs rarely, but is not known to breed; in Portugal, it is now believed to have disappeared.

[3]Excludes largemouth bass, which is now confirmed as extirpated, the last few specimens killed by an angler a few years ago (A.C. Pinder, pers. comm.).

[4]Includes (32 biol. non-native) species that have reproduced at least once in the wild, but only 23 have established populations, with 36 non-native species considered (included in Atlas of the French's Freshwater Fish Fauna).

[5]Anadromous contains sturgeons (five species) and *Alosa immaculata*, although all but one sturgeon thought to be extinct (not found in last 10 years). Dispersal includes common carp and Prussian carp, with the native origin of the former still in dispute.

[6]Excludes intensively stocked, but not biologically naturalized species (i.e. *Aristichthys nobilis*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*).

[7]Includes two species for which biological establishment is suspected but not confirmed.

[8]Includes *Carassius auratus/gibelio* for which it remains unknown whether introduction was intentional or not.

[9]Includes all introduced and extinct species.

[10]Derived from Bănărescu (1994) and Nalbant (2003).

[11]Total number of species and number of extinct native species in USA was compiled from http://www.fishbase.org (Froese and Pauly, 2000); all other USA data were compiled from Fuller et al. (1999). Breakdown of intentional and unintentional introductions derived by assuming that the proportional breakdown for translocated and non-native fishes combined (Fig. 6 in Fuller et al., 1999) applies to non-native fishes alone.

time (UK, England and Wales) has a relatively high number of intentionally introduced species, although less than half that of France and Russia (Table 1). In Italy, where controls on legal and illegal introductions and translocations for more than a century have been generally ineffective or absent, the number of unintentional non-native introductions is the highest in Europe, threatening local fauna and contributing to the extirpation of approximately 70% of native species (Bianco, 1995).

The motives for, and mechanisms by which, non-native fish species have been introduced have been many and varied. The primary motivation was for extensive fish culture, followed by ornamental (garden and aquarium) purposes, sport fishing, intensive aquaculture, or the 'national good' (i.e. acclimatization societies). The earliest recording of a freshwater fish introduction in most European countries is that of the common carp. The origin (Asian or European) of the common carp remains disputed (e.g. Balon, 1995; Froufe et al., 2002), but the first records of common carp about 6000 to 7000 BC indicate that it is native to rivers draining into the European part of the Ponto-Caspian region (Tsepkin, 1995). If so, then natural westward expansion of carp involved an intercontinental displacement, as the frontier between Europe and Asia divides the Black and Caspian seas (Fig. 2). This long history in Europe, combined with the species' ability to survive long periods outside water when kept moist, has resulted in numerous translocations between and within Europe and Asia. Introductions of common carp to Western Europe as a food item about 2000 years ago were most probably facilitated by the Romans (Balon, 1995) and later by monastic activities, which began in Italy (Bianco, 1998). The importance of common carp as a food stuff is apparent in historical documents, such as those from Bavaria in which the King of Bavaria is described to have sent his army to Bohemia to capture the Bohemian Cistercian monks and bring them to Bavaria to exploit their excellent knowledge on pond construction and artificial carp reproduction (H. Rosenthal, personal communication). Records from Ausonius (310–393 AD) do not mention the presence of common carp in the Rhine or the Moselle and all subsequent records can be explained by

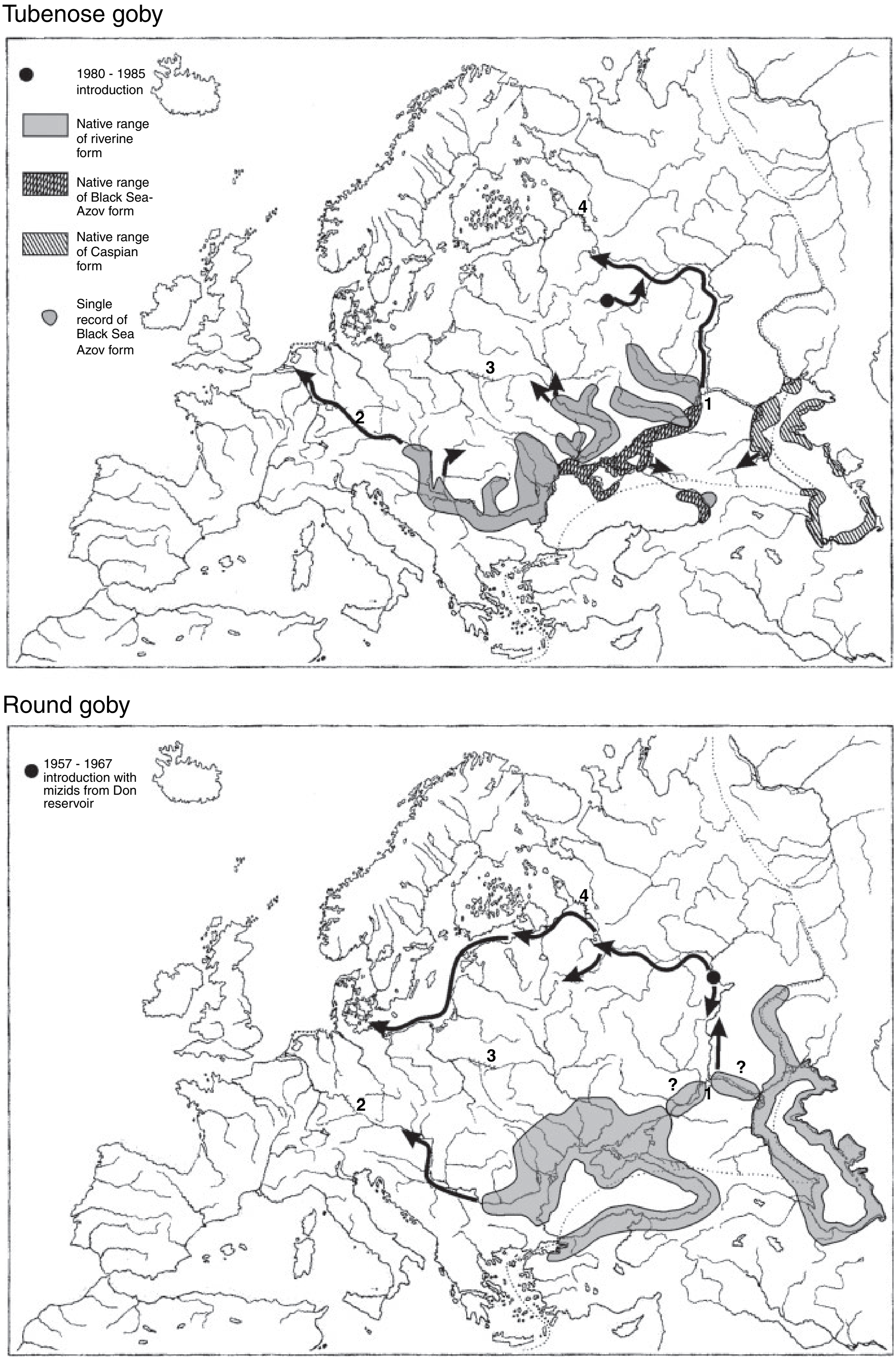

Fig. 2. Map of European with previous and expanded distribution of tubenose goby *Proterorhinus marmoratus* (re-drawn after Miller, 2004, with modifications after Naseka et al., 2005; E. Winter, pers. comm.) and round goby *Neogobius melanostomus* (re-drawn after Miller, 2003, with modifications after: Wiesner et al., 2000; Kostrzewa and Grabowski, 2002; Guti et al., 2003; Repečka, 2003; Stráňai and Andreji, 2004; Erős et al., 2005; Jurajda et al., 2005; Wiesner, 2005; V. Kováč, unpubl. data; R. Repečka, pers. comm.; G. Zauner, pers. comm.). Canal systems are: (1) Volga-Don, (2) Rhine–Main–Danube, (3) Pripyat-Bug, (4) Volga-Baltic Canal. Question mark indicates absent or unreliable evidence for that area

escapees from aquaculture *stricto senso* (e.g. Hoffmann, 1994; Balon, 1995). The date of common carp introductions to European countries varies, even between neighbouring and politically associated countries, and thus was not a gradual westward spread. For example, common carp was introduced to Poland and Prussia during the medieval ages (12th/13th century), probably transferred there from Middle Europe (Bohemia, Czech Republic) by Cistercian monks and reared in monastery ponds for food (Witkowski, 1996a). As early as the middle of the 15th century, monks are thought to have introduced common carp to England (Lever, 1977). But the species' introduction to Lithuania, which borders Poland, was not until the 17th century (Virbickas, 2000), probably a belated consequence of the country's conversion to Christianity in the 14–15th century. The introduction of common carp, along with goldfish *Carassius auratus*, to Spain and Portugal also occurred in the 17th century (Lozano-Rey, 1935) and probably in the 19th in Portugal (Almaça, 1995). Common carp was also the first fish species to be introduced to North America from Europe, with the first intentional introductions reported for Ontario (Canada) and in the Hudson River (USA) in the mid-1850s (e.g. Mills et al., 1993). Northward expansion of carp in North America was rapid, about 40–80 km a year between the 1950s and 1980s, and the species established many stunted, self-sustaining populations in various river and lake systems. Whereas in Europe, despite several centuries of aquaculture, there are relatively few self-reproducing populations and common carp is listed in several areas of central Europe as threatened or endangered, with the Danubian 'wild' form of carp being particularly rare (Krupka et al., 1989) or probably extinct (K. Hensel, pers. comm.).

Releases of common carp in Europe eventually became linked with those of the goldfish and/or the gibel carp *Carassius gibelio*, which were imported to Europe from Chinese aquaculture around 1611–1691 (Valenciennes, 1829–1848). We note here that the taxonomic status of gibel carp remains a subject of debate (e.g. Kottelat, 1997; Vasilieva and Vasiliev, 2000; Hänfling and Harley, 2003; Tóth et al., 2005). In the present paper, we use the species names provided by the respective contributors. The physical similarity of the brown variety of goldfish, gibel carp and crucian carp *Carassius carassius* has resulted in these introduced species being mistaken for native crucian carp (e.g. Vetemaa et al., 2005). In the UK, the crucian carp was originally believed to have been introduced along with common carp (e.g. Maitland, 1972) but has since been re-classified (Wheeler, 2000) as native to south-east England (see Copp et al., 2005b).

The sequence of goldfish introduction throughout Europe was equally varied to that of common carp. Goldfish arrived in Portugal in 1611, followed by England, France and Spain sometime during the 17th century (Lever, 1996), the first consignment around 1750 being that of the director of the 'Indies Company' at the port of Lorient, Britanny (Lever, 1996). Goldfish were imported to Germany, the Netherlands, Russia and Sweden in the early 18th century (as ornamental fish; Lever, 1996) and then into Lithuania in 1852 (probably an unintentional introduction with common carp) and to Hungary in 1891 for ornamental purposes. Arrival of gibel carp in the Lower River Danube (Romania) is also thought to have occurred in 1912 (Pojoga, 1977) as a consequence of natural spread down the Danube, and this was followed by declines in the native crucian carp populations (Manea, 1985). As with common carp, neighbouring countries experienced different introduction dates, with gibel carp *C. gibelio* being introduced to Poland eight decades later (i.e. 1930–1933) than in Lithuania, followed by an intentional introduction into Hungary in 1954 to fill a 'vacant niche' beside common carp (Tóth et al., 2005). Portugal and Italy are amongst the few countries to stock goldfish intentionally for angling, which in Portugal took place from 1983 to 1999 and in Italy continues to take place.

Repeated introductions and translocations of goldfish and gibel carp, including releases by the general public (Copp et al., 2005b), have resulted in an extremely wide distribution of this Asian taxon through Europe (e.g. Lever, 1996), being localized in some countries, e.g. Germany (Arnold, 1990) and Portugal (Almeida, 2002), but widespread in others, e.g. England (Maitland, 1972), Slovakia (Baruš, 1995), Italy (Bianco, 1998), Lithuania (Virbickas, 2000) and the Czech Republic (Halačka et al., 2003). After establishment, a lag phase in expansion occurred in some systems, followed by invasions of all suitable aquatic environments (e.g. Vetemaa et al., 2005). For example, the (rapid) dispersal of gibel carp in the Danube catchment began about a decade after its first appearance in the system, following a transfer from Bulgaria to ponds in Hungary in 1954 (Tóth et al., 2005); in the same year, the species was recorded in the adjacent Hungarian Danube (Tóth, 1975), then the Slovak Danube in 1961 (Balon, 1962) and the River Tisza in 1964 (Žitňan, 1965). Establishment of the gibel carp in the Danube was characterized by all-female, gynogenetically reproducing populations (Peňáz et al., 1979). This invasion coincided with the introduction of 'Chinese carps' (see below) and a decline of native crucian carp populations attributed to a shift from clear- to turbid-water-preferring species in the River Danube (Navodaru et al., 2002). Other Asiatic species, the so-called 'Chinese carps' (grass carp *Ctenopharyngodon idella*, silver carp *Hypophthalmichthys molitrix*, bighead carp *Aristichthys nobilis*) have also been introduced to Europe, e.g. in 1959 to Romania and in 1975 to Austria (Mikschi, 2002), with grass carp introduced to the UK during the 1970s (Stott, 1977). But these species have been able to establish in few systems outside their native range because of the absence of suitable conditions (in particular, insufficiently long unregulated water courses in which the pelagic eggs can incubate).

Amongst the most impressive East-to-West invasions of European inland waters in recent decades are those of topmouth gudgeon, the Chinese (Amur) sleeper *Perccottus glenii* and Ponto-Caspian gobies (see section 'East to West movements: intra-continental'). Topmouth gudgeon, which originates from a broad native range in north-eastern Asia (Amur basin, Korea, central and southern Japan, northern and central China and Taiwan), was accidentally imported in 1960 to a pond in Romania along with a deliberate introduction of larvae of various Chinese carp species (Bănărescu, 1964). Topmouth gudgeon then spread up the Danube and its tributaries (e.g. Tisza; Žitňan and Holčík, 1976) and into surrounding countries (e.g. Baruš et al., 1984; Cacik et al., 2004), including Austria by 1982 (Weber, 1984) and Italy (Bianco, 1988), established itself in every suitable lowland hydrosystem (*sensu* Petts and Amoros, 1996) in southern Slovakia and in Hungary, and was unintentionally introduced into the Rhine–Main–Danube Canal into the Rhine system, reaching Belgium and Holland. Soon after its arrival in Europe, topmouth gudgeon was also appearing in locations without an identifiable waterway vector, i.e. through fish introductions. For example, topmouth gudgeon was recorded (along with the odontobutid *Micropercops cinctus* in 1963) in a small, isolated lake in Lithuania following an introduction of grass carp. Topmouth gudgeon became a significant element of the fish assemblage in this lake within a few years, and then disappeared without any apparent cause after about a decade.

Subsequent introductions of topmouth gudgeon via importations occurred in England (mid-1980s), Italy (1987) and to Poland (1990), all presumably as a contaminant of imported cyprinids (e.g. Witkowski, 1991; Gozlan et al., 2002) from neighbouring European countries but also via the aquarium trade (e.g. previously sold in the UK under the name 'clicker barb'). The species now occurs in numerous natural and artificial hydrosystems throughout England and Poland. Through the same pathway (i.e. a contaminant of Chinese carp consignments), topmouth gudgeon was introduced to Kazakhstan, Uzbekistan and Kyrgyzstan (where it is now established in irrigation channels and lakes) and has been recorded in Albania, Denmark, Greece, Sweden, the former Yugoslav Republics of Macedonia and Montenegro (e.g. Lakes Skadar, Ohrid, Prespa and the Aliakamon), Bulgaria, Turkey (e.g. River Aksu, Anatolia), Armenia (e.g. River Aras), Iran and Algeria. In Europe east of the Danube, topmouth gudgeon has also been reported in Ukraine and Russia (e.g. rivers Dnieper and Dniester; many small rivers and lakes of the north Black Sea basin, from Moldavia to the Crimea Peninsula; numerous systems of Lower Don and Kuban; smaller rivers of the Sea of Azov). This rapid and extensive spread via aquaculture trade routes emphasizes the need for adequate quarantine and importation controls, even within the European Union.

A similar rapid and widespread expansion has been observed in the Chinese (Amur) sleeper, which was imported to St Petersburg (Russia) as an aquarium fish in 1912 and then introduced to a garden pond (Dmitriev, 1971). Subsequent releases of aquarium specimens into water bodies around St Petersburg were followed by the species' spread to the Baltic, to fish farms and to other Russian waters (Bogutskaya and Naseka, 2002). As a result of the formerly common practice in Poland of importing fish from the former Soviet Union (Terlecki and Pałka, 1999), the Chinese sleeper appeared in Poland in 1993–1994 in the River Vistula flood plain (Antychowicz, 1994) and is now present at numerous locations in the Vistula basin, including the western part of the River Bug in Poland (Brylinska, 2000), and it has crossed into the adjacent River Odra basin (Andrzejewski and Mastyński, 2004). How Chinese sleeper reached the Danube catchment remains unknown, but its first occurrence in the River Tisza catchment (Hungary) in 1997 (Harka, 1998) suggests that it arrived, as with topmouth gudgeon, through the aquaculture trade as a contaminant. Chinese sleeper was first recorded in Slovakia (River Latorica flood plain) in 1998 (Koščo et al., 1999), became extremely abundant in that area within one season (Kautman, 1999), then experienced a rapid decline in 2000 (V. Kováč, unpubl. data), followed by a rise in abundance in the rivers Latorica, Bodrog and Tisza (Koščo et al., 2003). The example of the Chinese sleeper underlies the potential risks of invasion posed by fish species via the aquarium trade (see Copp et al., 2005b).

The most westward expansion of some European species extends to the Great Lakes of North America, where ruffe *Gymnocephalus cernuus* and Ponto-Caspian gobies (in particular round goby *Neogobius melanostomus*) are amongst the last of hundreds of exotic aquatic plants and animals introduced since settlement of the continent by Europeans 400 years ago (Mills et al., 1993). Major periods of introduction of exotic species to North America occurred in the mid- to late 1800s with the initial influx of European settlers to the Great Lakes region. An early example (1883) of European fish introduction was the brown trout *Salmo trutta*, which is now established throughout most of eastern North America (Crossman, 1991) and has been identified as the cause of adverse ecological and genetic effects on a number of native North American salmonid populations (Krueger and May, 1991). A second influx of alien fishes began in the 1950s (Crossman, 1991). Large cities developed around strategic ports in the United States and Canada, as the Great Lakes had become the principal transportation route into North America. The opening of canal systems (the Erie in 1825, the Welland in 1829, the St Lawrence in 1847) and the St Lawrence Seaway (in 1959) corresponded to a direct increase in the number of introduced exotic species because these systems allowed trans-oceanic vessels to access the Great Lakes and ports throughout the Lakes (Hall and Mills, 2000).

The Great Lakes–St Lawrence River system on the Canadian–US border is thus a hotspot for exotic species (over 145 exotic species of invertebrates, disease pathogens, algae, fish and plants), with over half of the invading species being of Eurasian origin (Ricciardi and Rasmussen, 1998; Hall and Mills, 2000). Ballast water has been and continues to be the most important vector for the transport of invasive aquatic species worldwide (Carlton and Geller, 1993), and specifically to North America (Mills et al., 1993). For example, since the 1970s, 75% of the flora and fauna introduced into the Great Lakes has been linked to ballast water releases by ships of Eurasian origin (Ricciardi and MacIsaac, 2000). The successful invasion of the Great Lakes by the ruffe (Ricciardi and Rasmussen, 1998), was followed by that of Ponto-Caspian gobies, and in particular round goby, which was first reported in the Great Lakes in June 1990, subsequently spread, and has reached such high densities in some areas that reproduction and recruitment in native benthic fish species has been disrupted (Corkum et al., 2004).

East to West movements: intra-continental

The westward introductions of, and subsequent invasions by, fishes were not restricted to Asiatic species (assuming, in this example, that common carp is of Far Eastern native origin). Large-bodied piscivorous fish species have been introduced into Western Europe from their native ranges in Central/Eastern Europe, in particular European catfish *Silurus glanis* and pikeperch *Sander lucioperca* (also known colloquially in the UK by their German names, 'wels' and 'zander' respectively). Both of these species are now widespread in France (Keith and Allardi, 2001) and Italy (Bianco, 1998), and their ranges continue to expand in England and Wales (Copp et al., 2003; Maitland, 2004). Similarly, the expanded southern European distribution of some otherwise European species has occurred, such as for pikeperch and silver bream *Blicca bjoerkna* into Iberia, and various European species into Italy (e.g. whitefishes *Coregonus fera*, *C. macrophthalmus*, orfe (or ide) *Leuciscus idus*, gudgeon *Gobio gobio*, roach *Rutilus rutilus*, barbel *Barbus barbus*, Iberian barbel *Barbus graellsii*, Albanian roach *Pachychilon pictum*, nase *Chondrostoma nasus*, and common bream *Abramis brama* (Bianco, 1995, 1998; Bianco and Ketmaier, 2001). The introductions into Italy of others species, such as burbot *Lota lota*, Eurasian perch *Perca fluviatilis* and tench *Tinca tinca*, have been attributed to monastic activities being that there is no archaeological evidence (at least in Italy) of their use as food supply in the Holocene (Bianco, 1998).

Perhaps as a consequence of the pattern, in Europe, of decreasing freshwater fish species richness from East to West, a number of non-piscivorous fish species from the continent have been introduced, for ornamental and angling purposes, to the British Isles from Continental Europe, from Britain to Ireland, and from south-eastern England to the west and north of the island (see section Intra-country translocations). Introduction of the common carp from Continental Europe was followed by goldfish (and perhaps gibel carp) and then in the 19th century by rainbow trout, pikeperch, European catfish, orfe, largemouth bass and pumpkinseed (Lever, 1977). Subsequent fishes brought in from Europe were small-bodied, non-piscivorous species, such as bitterling *Rhodeus amarus* (sometime around the start of the 20th century), sunbleak *Leucaspius delineatus* and topmouth gudgeon (both mid 1980s), the latter two as intentional fish farm introductions (Gozlan et al., 2003). Introductions to the island of Ireland include common bream, silver bream and roach, the western limit (native range) of which was eastern England following the last ice age.

Amongst the most impressive East-to-West invasions within Europe in recent decades has been those of Ponto-Caspian gobies. In the last three decades of the 20th century, tubenose goby *Proterhorinus marmoratus* (Fig. 2), round goby (Fig. 2), monkey *N. fluviatilis* (Fig. 3) and Caspian bighead goby *Neogobius gorlap* (Fig. 4) all began to expand up the River Volga. These invasions have been facilitated by a range of factors, including species-specific traits such as phenotypic plasticity (e.g. Kováč and Siryová, 2005; L'avrinčíková et al., 2005), reproductive tactics (e.g. Grabowska, 2005) and low parasite loads relative to native species (Ondračková et al., 2005) as well as by human activities such as river regulation, the connection of contiguous basins by canals (Sapota, 2004; Naseka et al., 2005), ballast transport (Wiesner, 2005). For example, monkey goby and racer goby *N. gymnotrachelus* were able to continue their expansion up the River Dniester (Fig. 3) by crossing into the Vistula catchment (Poland) via the Pripyat-Bug canal system (Grabowska, 2005), which connects the River Vistula catchment (Baltic basin) and the River Dnieper catchment (Black Sea basin). In the River Danube, water retention structures constructed to facilitate energy production and navigation have resulted in a gradual increase in the mean annual and seasonal water temperatures. Coinciding with the general change in character of the Danube, four Ponto-Caspian gobies began to expand upstream of the 'Iron Gate', former Yugoslavia (Figs 2–4), the previous limit of their native Danubian distributions (Heckel and Kner, 1858; Bănărescu, 1964; Simonović et al., 1998). By the late 1990s, the expansion of bighead goby *Neogobius kessleri* (Fig. 4) and tubenose goby (Fig. 2) extended beyond the Middle Danube (Erős et al., 2005; Jurajda et al., 2005; Wiesner, 2005) into the Rhine catchment of Germany, via the Rhine–Main–Danube Canal (Freyhof, 2003), with tubenose goby already present in the Dutch part of the River Rhine (Fig. 2). The round goby appears to be making the same expansion, having been observed in Germany near Passau in 2004 (G. Zauner, pers. comm.). The Ponto-Caspian gobies are expected to invade all connecting river basins and lakes via canal systems (Dönni and Freyhof, 2002).

By the late 1980s and early 1990s, round goby had expanded up the Volga and, presumably via canals in the upper part of that system and ballast-water discharges, into the Baltic Sea (Sapota, 2004). The round goby has become one of the most abundant fish along the Polish Baltic coast and spreading eastwards into the Curonian Lagoon (Repečka, 2003) in Lithuania, and into the Kaliningrad region (Fig. 2). By the 1990s, the round goby had expanded up into the River Vistula, Poland, which was also experiencing an invasion (from a downstream direction) of racer and monkey gobies (Grabowska and Grabowski, 2005; Kakareko et al., 2005) from the East via the Pripyat-Bug canal system (Fig. 3).

West to East movements: inter-continental

The introduction of non-native fishes intensified in both Europe and North America during the mid- to late 19th century. During this period, the East-to-West introduction of common carp to North America (see above) was matched in the opposite direction by the introduction of North American species to Europe and Australasia. Introductions to Europe were facilitated, if not initiated, through the activities of the so-called 'acclimatization societies'. For example, the Society for Acclimatisation of Animals, Birds, Fishes, Insects and Vegetables within the United Kingdom (established in 1860) was responsible for the introduction of Continental European species to the British Isles (e.g. pikeperch, European catfish; Lever, 1977). The French equivalent was the Société Impériale Zoologique d'Acclimatation, which was established in 1855. In Germany, Max von dem Borne (1826–1894) was the pioneer of fish importations, which began in 1882 with the North American species (rainbow trout, brook trout *Salvelinus fontinalis*, brown bullhead *Ameiurus nebulosus*, pumpkinseed, smallmouth bass *Micropterus dolomieu* and largemouth bass). Similar programmes of non-native fish introductions followed during the late 19th century in other countries. For example, in Lithuania, M. Girdvainis (1841–1925) was responsible for the introduction of rainbow trout, brook trout, sterlet *Acipenser ruthenus*, and Peipsi whitefish *Coregonus maraenoides*. In Italy, the mid-19th century began a period of introductions of exotic species that increased with the establishment of two centres of ichthyology at Brescia and Rome in 1897–1898 (Bianco, 1995, 1998), with several North American species introduced (those mentioned above for Germany, plus black bullhead *Ameiurus melas* and channel catfish *Ictalurus punctatus*, and American lake charr *Salvelinus namaycush*). The motivation for these introductions was to increase the supply and diversity of aquatic food and game resources, both through natural production and in the new field of fish husbandry. In Iberia, where native obligate piscivorous fishes were lacking, an additional motivation in the 20th century was to fill this 'vacant' niche in the fish communities of newly created reservoirs, which were also popular angling sites. Thus, introductions of largemouth bass and northern pike *Esox lucius* coincided with introductions of forage species, e.g. pumpkinseed and bleak *Alburnus alburnus* (Godinho et al., 1998).

However, the novelty and ornamental value of these new species also played a part. For example, one of the stated aims of the UK Acclimatisation Society was 'The introduction, acclimatisation, and domestication of all noxious animals, birds, fishes, insects, and vegetables, whether useful or ornamental' (Lever, 1977). Motivations varied between countries for a given species. For example, the introduction of pumpkinseed in the late 19th/early 20th century was for angling in France (e.g. Künstler, 1908) but as an ornamental fish in England (Copp et al., 2002), Slovenia (Povž and Šumer, 2005) and Spain (García-Berthou and Moreno-Amich, 2000). Introduced pumpkinseed have demonstrated

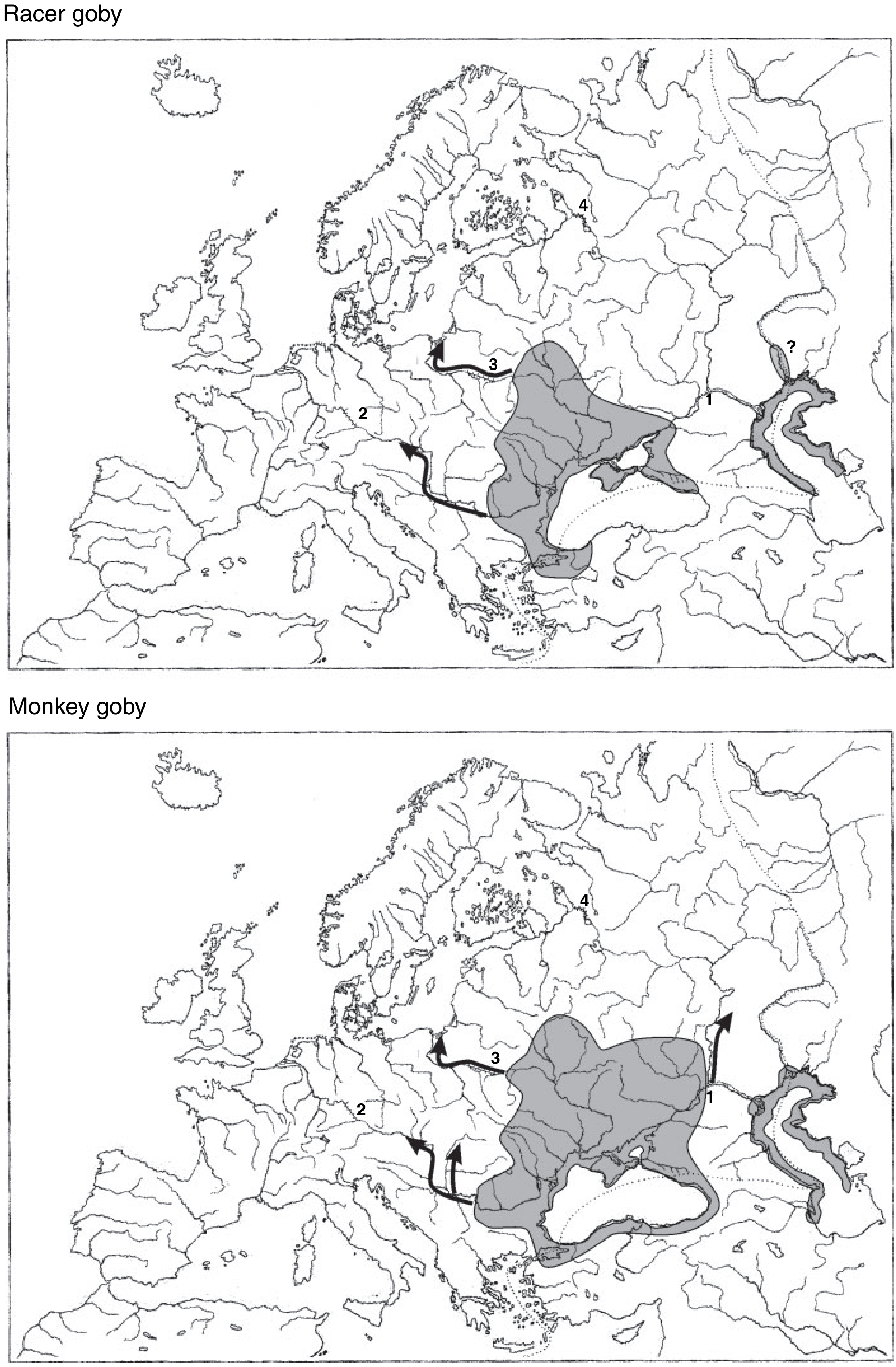

Fig. 3. Maps of European with previous and expanded distributions of racer goby *Neogobius gymnotrachelus* (re-drawn after Miller, 2003, with modifications after: Kautman, 2001; A. M. Naseka and V. Bodyrev, unpubl. data) and monkey goby *N. fluviatilis* (re-drawn after Miller, 2003, with modifications after: Harka and Jakab, 2001; Stráňai and Andreji, 2001; Jurajda et al., 2005; A. M. Naseka and V. Bodyrev, unpubl. data). Canal system names given in Fig. 2

Bighead goby (left) and Caspian bighead goby (right)

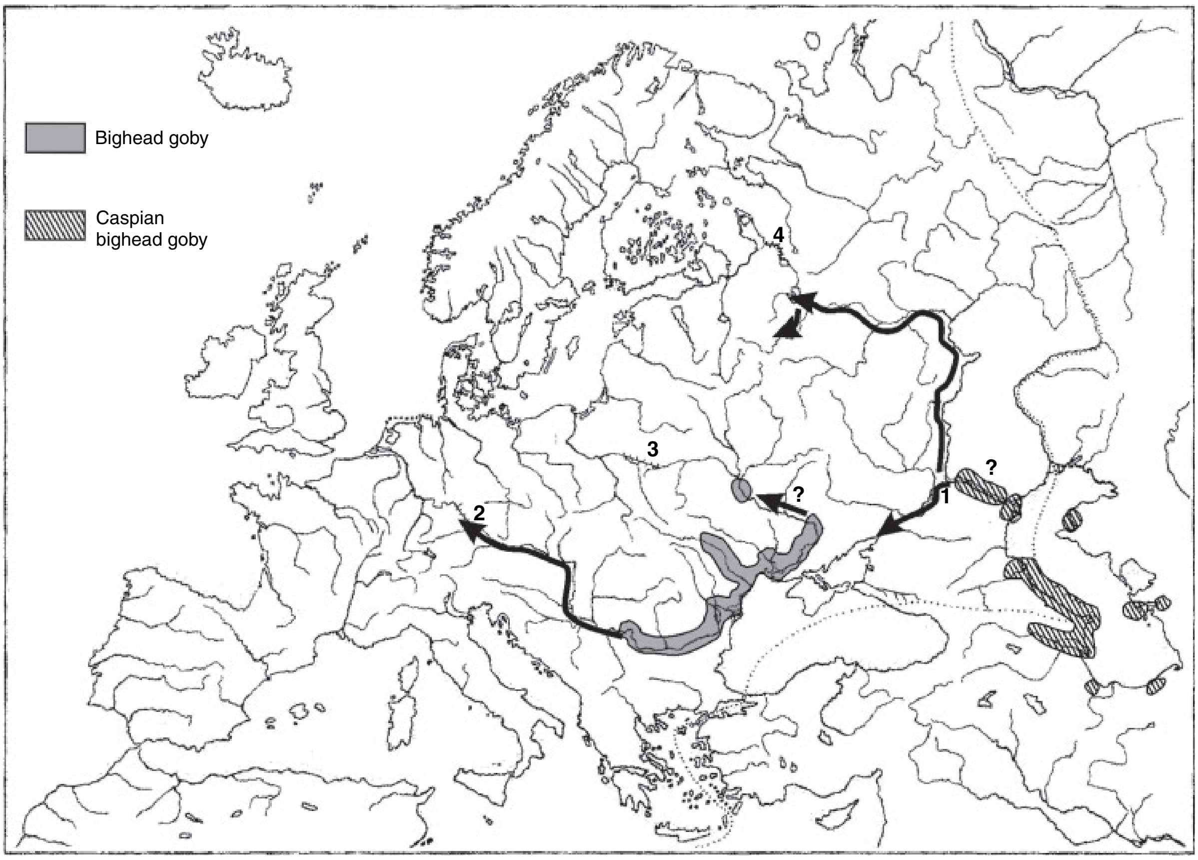

Fig. 4. Maps of European with previous and expanded distributions of bighead goby *Neogobius kessleri* (re-drawn after Miller, 2003, with modifications after: Seifert and Hartmann, 2000; Jurajda et al., 2005; V. Kováč, unpubl. data; A. M. Naseka and V. Bodyrev, unpubl. data) and Caspian bighead goby *Neogobius gorlap* (re-drawn after Miller, 2003, with modifications after: A. M. Naseka and V. Bodyrev, pers. comm.). Canal system names given in Fig. 2. Question mark indicates absent or unreliable evidence for that area

great plasticity in morphology (Tomeček et al., 2005; Šumer et al., 2005) and life history (e.g. Villeneuve et al., 2005), and the species is now established in at least 28 European countries. The greatest concern over pumpkinseed presence emanates from Iberia (e.g. Godinho et al., 1998; Elvira and Almodóvar, 2001). Of the North American salmonids, rainbow trout is one of few species to establish self-sustaining populations in Europe, and this is only when particular climatic and river discharge conditions are present (Fausch et al., 2001). Brook trout has also established in some locations, e.g. certain locations in Slovenia (Povž and Šumer, 2005), the River Grabia, Poland (M. Zalewski, pers. comm.). The mosquitofish *Gambusia holbrooki* was introduced to control mosquito larvae and pupae in certain parts of southern Europe, first to Spain in 1920, then Germany (1921), Italy (in 1922 from Spain) and then to most every European country as well as to Asia Minor as far as Levant basin in Middle East (Goren and Galil, 2005) and Iran in Middle Asia (Bianco, 1995). The species has done so well that it is now widespread and abundant in many warm-water systems. Mosquitofish was an effective effort against malaria but was detrimental to others fishes, especially Cyprinodontoidea (Ronchetti, 1968), endemic Iberian species of toothcarp (Caiola and de Sostoa, 2005) and possibly Levant silver carp *Hemigrammocapoeta nana*, common garra *Garra rufa* and the southern Dead Sea endemic, Sodom's garra *Garra ghoerensis* (Goren and Galil, 2005).

The introduction and dispersal patterns of introduced North American species have varied between European countries. Black bullhead, sometimes misidentified as brown bullhead, was introduced to some countries (e.g. France, Romania, Spain, Italy) in the late 19th/early 20th century, but only began to appear in other European countries in the 1980s (Pintér, 1998: Elvira and Almodóvar, 2001). Distribution patterns also varied, with black bullhead widely dispersed in some countries, e.g. Italy (Bianco, 1998), France (Keith and Allardi, 2001) and Portugal (Almaça, 1995), but localized in others: e.g. Spain (Lake Banyoles only: Doadrio et al., 1991), Germany (both black and brown bullhead; Arnold, 1990), and England (Lever, 1977). In the Danube basin, artificial propagation in Hungary of black bullhead in ponds was followed, nine years hence, by a population explosion in the wild whereby the species spread rapidly downstream to Lake Balaton (Hungary; Pintér, 1998) and into Slovenian tributaries of the Danube as well as upstream into side-arms of the Slovak Danube and its tributaries (Koščo et al., 2000). Brown bullhead and pumpkinseed populations in the lower Danube (Romania) are also thought to have been derived from downstream dispersal of escapee fish from Hungarian fish farms (Manea, 1985), whereas the origin of pumpkinseed in Slovakia remains unclear (Tomeček et al., 2005). The black bullhead's range in Slovakia continues to expand, and the same pattern is being observed in the Guadiana and the Tagus basins of Portugal, where black bullhead has rapidly established substantial populations, primarily in reservoirs (e.g. the newly filled Alqueva), and most recently in connected river systems.

Intra-country translocations

Translocations are most common in countries that encompass geographically distinct drainage basins, such as southern European peninsular countries (Spain, Portugal, Italy, western Balkans, Greece), the British Isles, Russia, Canada and the USA. Indeed, freshwater fish translocations have been so common in some countries (e.g. Italy, UK) for so long (numerous decades if not centuries) that it is difficult in some cases to determine the natural post-glacial ranges of some species. For example, eight decades of translocations in Italy (totally about 11.9 billion fishes from 32 species of which 16 were native) resulted in several endemic species (to northern Italy: e.g. alpine bleak *Alburnus arborella*, spined loach *Cobitis taenia*, lasca *Chondrostoma genei*) achieving nearly pan-Italian distributions (Bianco, 1995, 1998). A similar pattern took place in the UK, especially for species (e.g. cyprinids) of angling interest (see Davies et al., 2004), but most recently and notably have been translocations of ruffe and roach from their native range in southern–southeastern England to other parts of the island. Both of these species are thought to have been introduced accidentally when used as, or associated with, live bait and have been blamed for declines in native whitefishes *Coregonus* spp., although evidence for this remains elusive (e.g. Winfield et al., 1998) and the concurrent eutrophication of the lakes is a likely contributing factor in whitefish declines.

A very good example of successful translocation of a species for conservation purposes (at a national level) is that of the Danubian salmon (or huchen) *Hucho hucho* in Poland (Witkowski, 1996b). The native range of Danubian salmon in Poland was restricted to two small rivers (Czarna Orave, Czadeczek) of the Danube River basin. The species became threatened in these rivers as a result of over-exploitation (mostly illegal) and water pollution. However, self-sustained populations were established in two Carpathian tributaries (Dunajec and Poprad) of the River Vistula through intensive stocking. Danubian salmon is currently being stocked into water courses of the Odra catchment.

In North America, translocations of salmonids, centrarchids and percids have been common for recreational or commercial purposes (Mills et al., 1993). For example, rainbow trout, which is native to regions west of the North American continental divide (Rocky Mountains), has been introduced into every province in Canada, the Yukon and the Northwest Territories (Crossman, 1991). This species supports a significant recreational fishery and is valuable to the aquaculture industry. However, rainbow trout have displaced native brook trout through competition in areas where the two species overlap (Lohr and West, 1992). Similarly, in the Pacific Northwest states and the Canadian province of British Columbia, escapee Atlantic salmon *Salmo salar* from cage-culture facilities (Volpe et al., 2001) have been captured in the region (Thomson and Candy, 1998). Naturally reproduction of Atlantic salmon, on the northeast coast of Vancouver Island, has been reported once (Volpe et al., 2000) but not subsequently, and this could be cause for concern due to the potential and observed (Volpe et al., 2001) adverse effects of this non-native species on the already-declining populations of native Pacific salmonids.

In Russia, which occupies the Palaearctic Realm (Arctic, western Pacific, Caspian, eastern Atlantic), taxonomic composition and species richness differs greatly between geographical regions. The vast northern glaciated areas are species-poor because of relatively slow postglacial re-colonization in the severe climate. In the western and southern regions, fish diversity is considerably higher. Intentional fish introductions for fisheries and aquaculture releases are prominent and have a long history, mainly to enhance local (put-and-take) fisheries rather than for intensive aquaculture. In the 1960–1970s, there was a dramatic increase in the numbers of fish introduced, involving up to 400 translocations into up to 370 water bodies each year. For example, gorbusha pink (or hunchback) salmon *Oncorhynchus gorbusha* were intentionally introduced (for commercial reasons) in the White Sea basin, where it now threatens the native Atlantic salmon through competition for spawning sites. This contrasts the interaction of Atlantic and native *Oncorhynchus* species described above for the Canadian Pacific coast. Canal construction, mainly for irrigation and transport, was particularly important and linked otherwise unconnected water bodies throughout Russia. The basins of the Arctic Ocean, Caspian Sea, Black Sea (with Azov Sea) and Baltic Sea have been connected, with the most pronounced example being the River Volga. These connections have facilitated the dispersal of fishes from their native ranges into new areas (e.g. Black Sea and Caspian sprat *Clupeonella cultriventris*, *Benthophilus* tadpole gobies, needle fish *Syngnathus abaster* immigrations through the Volgo-Don Canal), as well as the expansion of intentionally or accidentally introduced species (e.g. Chinese sleeper, Ponto-Caspian gobies).

Patterns in legislation and policy regarding non-native freshwater fishes

European legislation

It is evident from national policy and legislation that attitudes to the introduction of non-native fish have changed over time. In many countries, as noted above, efforts have previously been made to seek out and introduce new species actively. For example, government departments in the UK and elsewhere were engaged as recently as the late 1970s in evaluating the potential use of a non-native species (i.e. grass carp) as an alternative means of aquatic weed control (Stott, 1977). Indeed, grass carp introductions to control plant outgrowths, especially exotic species (water milfoil *Myriophyllum aquaticum*, water hyacinth *Eichhornia crassipes*), continues in countries such as Portugal, where it was released in confined environments during the early 1990s. In the former USSR, fish stocking and introductions (under the term of 'acclimatization', e.g. extensive aquaculture and establishment under natural conditions) were 'Tasks from Government' in annual and 5-year Soviet State Plans that had the character of state laws (necessitating completion). Within a number of sectors, there is still active interest in the potential for importing and rearing new species.

The ornamental aquatic trade in many countries remains keen to develop trade in non-native freshwater fish species, both tropical and temperate, with virtually no import restrictions in some countries (e.g. Germany) on the numbers and species of tropical fish. Similarly, in the UK, which has relatively stringent controls (for Europe) on the importation of temperate fish species, tropical fish imports remain largely uncontrolled (presumably because it is thought that they cannot establish self-sustaining populations in the wild). In Iberia, for example, the introduction of the cichlid *Cichlasoma facetum* is believed to be related to aquarists' releases. With advances in aquaculture technologies, there is also interest in the potential for rearing new species for food, and there is continued interest in introducing novel species to provide specialist angling fisheries. However, the increased concern worldwide about the adverse impacts of non-native species, including fish (Allendorf, 1991; Wheeler, 1991), and the resulting cost implications (Mills et al., 1993: Hall and Mills, 2000; Perrings, 2002) have led many countries, especially following the Rio Declaration, to adhere to international agreements (e.g. FAO, 1998) that adopt a 'precautionary approach' to the conservation and management of fish stocks and to species introductions. Additionally, some ornamental trade organizations (e.g. the Ornamental Aquatic Trade Association; http://www.ornamentalfish.org) promote guidelines to avoid the release of ornamental fishes to the wild.

In developing legislation to regulate fish movements and introductions, and to safeguard native biodiversity, government authorities have thus been faced with changing attitudes and conflicting views. Decisions have been required in relation to the status of different species, for example, to determine whether these should be regarded as acclimatized or non-native. In addition, the views and requirements of different sectoral interests, and socioeconomic issues such as levels of established trade (and the need to observe free-trade requirements) have needed to be considered in order to ensure that any new measures are reasonable and proportionate.

The pieces of legislation that govern the movements and transfer of freshwater fish in Europe and North America are varied both in their intended policy and the history of their development within a wider environmental protection and conservation context (Table 2). The commonality in most European legislation is a prohibition on fish introductions except under licence or consent. However, differences emerge in the specification of what may not be introduced. In some countries (e.g. France, Italy, Slovakia), legislation refers specifically to non-native (or alien) species whereas in others it refers to species 'not ordinarily resident' or 'not occurring' in the country in question. The latter lacks the biogeographical

Table 2
Enactment dates for policy and legislation (P & L) in selected European and North American countries as regards environmental protection and conservation (Env. Protect. & Conserv.), fish stocking, non-native species (including the release of alien species to the environment and their keeping under controlled conditions: i.e. aquaculture, scientific, aquarist purposes), and non-native species risk assessment

Country	Env. Protect. & Conserv. (P & L)	Fish stocking (P & L)	'Modern' practice since	Non-native species		Risk assessment	
				P & L release	Keeping	P & L	Framework
Austria	1983[1]	since 1983[2]	15th century/1880[3]	since 1983[2]	since 1983[2]	no	no
Canada			mid-to-late 1800s	1995[4]			
Czech Republic	1992[5]		1882	1990[6], 1995[7]			
England& Wales	1990[8]	1975[9]	1860[10]	1980[11], 1981[12]	1998[13]	1995[14]	2004[15]
France			1843[16], 1855[17]	2000[18]	1985[19]		
Germany	1998[20]		1882[21]				
Hungary	1996[22]		1888[23]	1996[24]			
Italy				2003[25]			
Lithuania	1992[26]	2000[27]	1885[28]	2002[29]	no	no	no
Poland	1991[30]		1881–1912	1985[31]			
Portugal	1999[32]	1959[33a], 1962[33b]	2000	1999[32]	1999[32]	1999[32]	1999[32]
Romania	1995[33]	2001[34]	1956	2004[35]			
Russia	1982[36], 1995[37], 1996, 2003[38]	from 1928[39]	1850s[40]	2002[41]	2002[42]		
Slovakia				2002[43]			
Slovenia			1891[44]	1976[45], 1993[46]			
Spain	1989[47]	1989[48]	during 20th century	1989[47]	1989[48]	no	no
USA			mid-to-late 1800s	1990[49], 1993[50], 2003[51]			

Also given are the known, or approximate, dates for 'modern' practices of stocking (i.e. intensification of aquaculture and institutionalized stocking for professional and private fisheries, usually in the 19th century and distinct from earlier monastic stocking of common carp).
[1]Ratification of Bern Convention, then onset of integration into provincial laws. [2]Complexe of provincial laws updated on *ad hoc* basis (e.g. Bern Convention recommendations on non-native species not yet incorporated). [3]Medieval monastic stocking of rivers and lakes; stocking of high alpine Tyrol lakes in 15th/16th century with *Salvelinus alpinus*, then *Salvelinus fontinalis* in 1880 and *Oncorhynchus mykiss* in 1884. [4]Canadian Biodiversity Strategy. [5]Ministry of Environment Act No. 114 'Protection of Nature and Landscape'. [6]See RIFHV (1990). [7]See CzMA (1995). [8]Environmental Protection Act. [9]Salmon and Freshwater Fisheries Act. [10]Society for Acclimatisation of Animals, Birds, Fishes, Insects and Vegetables within the United Kingdom. [11]Import of Live Fish Act. [12]Wildlife & Countryside Act. [13]Prohibition of Keeping or Release of Live Fish (Specified Species) Order. [14]See UK DoE (1995). [15]See Copp et al. (2005a). [16]See Haxo (1853). [17]Société Impériale Zoologique d'Acclimatation. [18]Code de l'environnement, article 411-3. [19]Décret no. 85-1307, 9 December (i.e. introduction into closed water bodies for scientific or aquaculture purposes). [20]Bundesumweltministerium, 1998 (see text). [21]Max von dem Borne (1826–1894). [22]Act No LIII on Nature Conservation in Hungary. [23]Described in Herman (1888). [24]Act No LIII, Article 14. [25]Law on protection of wild fauna and flora, GU n. 124 of 30 May. [26]Law on Environmental Protection of the Republic of Lithuania, 21 January; [27]Law of Fishery of the Republic of Lithuania, 12 July; [28]Initiative of M. Girdvainis (see text); [29]Introduction, Reintroduction and Transfers, Control and Extermination of Invasive Species Organisms, Approval of the Composition and Provisions of the Invasive Species Control Council, Ministry of Environment Order No. 352, 1 July; [30]Nature Protection Act (October); [31]Inland Fishery Act (April); [32]Executive Law no. 565; [33a]Law 2097 (Fisheries Act); [33b]Executive Law no. 44623; [33]Environmental Protection Law; [34]Environmental Protection Law (revised); [35]Environmental Protection Law (further revised to incorporate CITES Convention of 1973, Washington, D.C.); [36]Law on Protection and Use of Animal World (USSR era); [37]Law on Animal World (Russian Federation era); [38]Act No. 158 'On Red Data Book of Russian Federation', updated on 24 April; [39]Fish stocking and introductions (under the term of 'acclimatisation'), included (before collapse of USSR) annual and five-year State plans; [40]Establishment of first fish farm (Nikolsky) to promote fish introductions throughout the Russian Empire; [41]Ecological Doctrine of Russian Federation, approved 31 August; [43]Nature and Landscape Protection Act No 543 Z.z; [44]See Povž and Ocvirk (1990); [45]Freshwater Fisheries Act (OG SRS 25); [46]Decree on the closed season and minimal size of catchable fish, crayfish and mussels (OG RS 14); [47]Natural Areas and the Wild Flora and Fauna Conservation Act; [48]Hunting & Fishing Species Trade Order; [49]Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA); [50]Act of U.S. Congress; [51]US National Aquatic Invasive Species Act.

basis of the former. Additionally, the legislation and practice are in some cases conflicting or contradictory, even within a country. For example, in Slovenia the Ministry for Agriculture and Forestry is responsible for management of aquaculture and recreational fishing and the Ministry for Environment, Planning and Electricity is responsible for the conservation of endangered fish species; they have opposing interests and the level of cooperation between them could be better. To avoid potential conflicts of this type, Portuguese legislation (Table 2: Exec. Law no. 565/99) specifies that the consent for the introduction of an exotic species must be given by both Environment and Fisheries Authorities.

In federal states, such as Germany, Austria and Italy, national laws on nature protection and non-native species regulation may be less common than state or provincial laws. For example, all nine of the Austrian federal provinces have their own legislation concerning fisheries and the conservation of nature. Consequently, variations exist between them in the details of protective measures that apply (e.g. time-span, size of fish) as well as in the restrictions on stocking (river-type specific, native, or naturalized species). A national framework is currently under discussion. A similar situation exists in Italy, when in general there are no particular national laws to protect endemic freshwater fish species. However, a recent national law (Table 2) stipulates that 'introductions, re-introductions, and stockings into the wild with non native species or populations are forbidden'. In practice, each of the 102 provinces make their own rules, which are strictly or loosely applied, depending from local authorities. These laws are regularly ignored and, due to a general little knowledge of fish taxonomy and endemic forms, legal introductions for instance of *Barbus* species do not discriminate between native or imported species.

In virtually every country, the legislation contains named derogations, or administrative protocols that can allow exceptions to be made, that permit non-native species introductions. This legislative confusion as regards non-native species introductions is achieved in two contrasting policy approaches, which are exemplified in the UK and French legislation (Table 2): the UK Wildlife and Countryside Act 1981 (WCA) and the French Code de l'environnement (Article 411-3). Both of these laws provide for controls over the introduction of non-native (fish) species, but the wording of the two pieces of legislation provide two different means by which an outright restriction on non-native introductions can be circumvented.

The WCA, executed by the Department for Environment, Food and Rural Affairs, makes it an offence to release, or to allow to escape into the wild without licence, any species (or a kind) not ordinarily resident in or a regular visitor to Great Britain in the wild state. For the purposes of this legislation, it was necessary to determine whether a species (or kind) should be regarded as 'ordinarily resident', and the outcome has been less than consistent. For example, common carp have been present in the UK for a number of centuries, they are widespread and of great commercial value (angling amenity and ornamental fish trade, i.e. koi), and thus they have been categorized as ordinarily resident. Similar decisions were also reached in respect of the popular ornamental species goldfish and golden orfe. In contrast, a number of fish species (e.g. pikeperch, European catfish, pumpkinseed) were introduced to the country at the same (acclimatization society) era as golden orfe (see Lever, 1977), and have become established at least in some areas, were specifically listed within WCA as 'not ordinarily resident'. Whereas, rainbow trout was treated as a special case under WCA, because of its value in aquaculture and for stocking in put-and-take fisheries, and a general licence was granted authorizing their use despite potential risks to native species but subject to other numerous controls. A remarkable aspect of this legislation is that species thought to be extirpated in the UK, for example the burbot, are subject to licensing under the WCA because they are no longer 'ordinarily resident' in the UK (and any fish used in a re-establishment programme would necessarily be derived from non-native stocks). Whilst it might seem odd to subject extirpated native species to controls that are not imposed on 'ordinarily resident' non-native fishes (e.g. common carp, goldfish), this does ensure that national and international criteria (e.g. IUCN, 1987) for re-introductions are met, that the re-introduction forms part of a biodiversity action plan and the reasons for the original extirpation have been removed prior to consent being given.

Enacted a year earlier, the Import of Live Fish Act 1980 (ILFA) was implemented to provide controls on the importation of fish species, including non-native, and thus protect native fish and their habitat. However, unauthorized spread of non-native fishes continued, so 'The Prohibition of Keeping or Release of Live Fish (Specified Species) Order' was enacted in 1998. This order includes a list of the species subject to control that is subject to revision, e.g. The Prohibition of Keeping or Release of Live Fish (Specified Species) (Amendment) (England) Order, 2003). The most significant aspect of these new measures is that they have extended controls to the keeping of non-native species for commercial and private purposes (e.g. fish farmers, fish dealers, ornamental trade, aquarists). These new measures are intended to be precautionary and provide a general presumption against the keeping or release of any new species and a presumption against the release of any of the listed species to open waters. However, exceptions have had to be made to allow for species already established (e.g. pikeperch, pumpkinseed, bitterling) or being kept (fathead minnow). The keeping and release of these species may be permitted subject to conditions, which will vary according to the level of risk posed by the species. Despite much publicity, many people are either not aware of the law, not aware that the species in their possession is ILFA listed (e.g. if the fish were obtained prior to the 1998 legislation), or not aware that the species in fact exists in waters (pond or stream) on their property (and that existence often pre-dates ILFA).

Somewhat similar to UK legislation (WCA + ILFA) is the Polish Nature Protection Act (Table 2), which prohibits the introduction, to the natural environment, of animals and plants, and any of their development stages, that are not native to Poland. This is complemented by the Polish Inland Fishery Act, which states that any introduction of fishes that do not occur in Poland requires consent from the Polish Ministry of Agriculture and Rural Development; this consent is granted with agreement from the Polish Ministry of Environment, which in turn is obliged to consult the State Council for Nature Protection. Reference in the Act to 'fishes that do not occur in Poland' is assumed to mean non-native species, though this is not precisely stated, and as such resembles the UK status of 'not ordinarily resident'.

In Spain, the Natural Areas and the Wild Flora and Fauna Conservation Act (Table 2) takes a generic approach, prohibiting the introduction of any fish species, sub-species or races into an inland water without administrative consent. This applies to both native and non-native species, permitting the control of translocations of native species within Spain as well as the introduction of alien species. As with UK law, the re-introduction of fish species that have become nationally extirpated is also subject to licensing in order to safeguard genetic diversity.

In France and Slovakia, the Code de l'environnement (Article 411-3) and the 'Nature and Landscape Protection Act', respectively, forbid any introduction of species non-native to those countries (Table 2). In France, however, the Prime Minister has the power, with advice taken from the Minister of the Environment, to authorize non-native introductions for scientific purposes or for aquaculture in closed water bodies (décret no. 85-1307 of 9 December 1985). In practice, the minister in charge of freshwater fisheries has used his power, after consultation with the 'Conseil National de Protection de la Nature' and the 'Conseil Supérieur de la Pêche', to promulgate a decree that includes a list of fish species not present in French inland waters (Code Rural: Article 413) that may be introduced under licence and associated with specific technical conditions. The introduction of any other non-native species must be done after consultation by the minister with the two councils and is time limited (30 years) but renewable. Despite these regulations, it is still difficult to control the introduction of exotic fish species in France because each case is species and site specific. In Slovakia, a list of 'invasive' fishes (*sensu stricto*, see below) has been prepared recently (Kováč et al., 2005).

The French legislation on non-natives is largely characteristic of that enacted by many other European countries (e.g. Germany, Lithuania) in that the main legal Act prohibits the introduction of non-native fishes. However, some countries (e.g. Poland, Lithuania) do not attempt to generate comprehensive lists of what is either native (uncontrolled) or non-native (controlled) species but rather rely upon an advisory body to assess each proposed introduction on a species-by-species, case-by-case basis. Indeed, only two alien fish species are mentioned by name in the Lithuanian legislation as undesirable (or invasive) 'weeds' (Chinese sleeper and round goby) and as such should be controlled or/and eradicated (Order No. D1-433 of 16 August 2004; 'Approval of the List of Invasive Species in Lithuania'). Similarly, in Poland, only three species are mentioned. Under Lithuanian Ministry of Environment Order No. 352 (Table 2), introductions or transfers of non-native species are allowed only if the Lithuanian Invasive Species Control Council (ISCC) concludes that the spread of the introduced species would not result in adverse ecological, economical effects and would not constitute a hazard to human health. However, the main fish species reared in aquaculture and stocked in Lithuania are non-native (common carp, rainbow trout, northern whitefish, grass carp) and known to have negative impacts in other countries (e.g. Crivelli, 1983; Moore et al., 1986; Maceina et al., 1992; Mamcarz, 1992). Despite this, only the introduction of rainbow trout is mentioned in the ISCC resolutions. A potentially conflicting piece of Lithuanian legislation is the Ministry of Environment and Ministry of Agriculture Order No. 404/536 of 11 October 2002 (Instructions for Fish and Other Aquatic Animals Stocking; Table 2), which recognizes that the transfer and stocking of non-native species is regulated under Order No. 352 (see above) but nonetheless provides guidance on the standard stocking rates (minimum, intermediate, maximum) for common carp and northern whitefish in water bodies, subject to permission from the ISCC. In practice, there is little restriction placed on the transfer of the non-native fishes of importance to aquaculture and in most cases, such transfers take place in open water systems. Stocking consents are granted by the Fishery Department and is essentially a formality for commonly used non-native species. For example, the release of rainbow trout into open lake systems in some Regional Parks is financed by the State (Order No. 3D-101 of 9 March 2004; 'Approval of Programme of Fish Stocking in Water Bodies of State Importance'), despite the ISCC's decision to prohibit the species' introduction into open water systems (K. Arbačiauskas, ISCC, pers. comm.). In the Czech Republic, the procedure is similar. The stocking of non-native species of animals and plants is forbidden by the Act No. 114/1992 (Table 2), but exceptions for fish may be given by the Ministry of Agriculture upon recommendation from its 'Commission for Introduction of Fishes and Aquatic Invertebrates' (established in 1994), which uses the 'Guidelines for Introduction of fishes and aquatic invertebrates' (Table 2) when making decisions.

Another common element of legislation in European countries is the specific naming of example species as 'invasive'. Lithuanian legislation designates Chinese sleeper and round goby as 'invasive', whereas Portuguese legislation (Table 2) classifies pumpkinseed and mosquitoefish. In Spanish legislation, which stipulates that 'non-native' or 'exotic' species refers to all species not native to Spanish fresh waters (including species introduced some centuries ago), the example 'invasive' species are common carp and goldfish.

The above examples illustrate that the current status of non-native species has diverged from a simple biogeographical focus in most European countries, with the exception of Spain. Even there, some anglers and most of the general public are unaware of the legal status or even taxonomic identity of the various fish species. The same can be said of many other countries. In dealing with fish introductions, socioeconomic and political issues and the views of stakeholder groups need to be taken into account in developing legislation and appropriate controls. The categorization of species and the legislative rigour has thus been influenced by a need for pragmatism and practicality, as well as consideration of ecological issues. For example, in Portugal, the introduction of an exotic species is allowed only when: (i) an obvious need for human purposes is demonstrated, (ii) no indigenous species can fulfil this need and (iii) there is scientific evidence that the risks of introduction are minimal. So far, only the grass carp has been proposed for introduction to Portugal and permission therefore is under investigation. In Spain, and despite recent legislation, non-native fish species continue to be introduced, such as Siberian sturgeon *Acipenser baeri*, channel catfish, *Ictalurus punctatus*, silver bream, *Blicca bjoerkna* in 1995 as well as Mediterranean toothcarp *Aphanius fasciatus*, first reported in 1997, and guppy *Poecilia reticulata*, which apparently established in 2000 (Elvira and Almodóvar, 2001). Clearly, there is need for a more proactive approach based on risk analysis (e.g. Copp et al., 2005a; see also http://www.cefas.co.uk/publications/techrep/tech129.pdf).

Legislation and translocations

Probably least regulated amongst fish movements are translocations of fish (whether native or non-native) within a political state, which for fisheries and aquaculture have been common in many countries. For example, in the former USSR, where fish introductions have a long history in enhancing local 'put-and-take' fisheries, there was a dramatic increase in fish translocations in the period 1960–1970 (400 translocations into up to 370 water bodies each year). In England and Wales, the Salmon and Freshwater Fisheries Act (Table 2) was enacted to control such translocations, making it unlawful to stock any fish or spawn of fish (native or non-native) into an inland water without written consent. Similar legislation to control internal fish transfers exists in other countries such as France and Spain (Table 2), but fish translocations and introductions remain common place in Europe, and the decisions to consent transfers have been driven primarily by commercial (angling, aquaculture) interests, often with no clear and implemented strategy to conserve the genetic integrity of native fish populations nor the taxonomic character of indigenous fish assemblages. Although such a strategy exists for brown trout and grayling *Thymallus thymallus* in the UK (UK EA, 2003), none exists for the translocation of other species, such as introductions of barbel to river catchments outside its native range of south-east England and the introduction of non-native orfe to stillwater fisheries. These transfers have been linked in some cases with the dispersal of invasive non-native species. For example, topmouth gudgeon was introduced into a golden orfe fish farm in southern England in 1985 and then spread from this location to other parts of England and Wales as contaminants of authorized movements of golden orfe (Gozlan et al., 2002). In Catalonia (Spain), the European catfish is both alien and extremely popular with anglers (especially from Germany and the UK); its initial introduced range was restricted to the Ebro River basin, but the species has recently been reported as established in reservoirs of north-eastern Catalonia outside the Ebro catchment.

North American legislation

Despite an increasing awareness of the major ecological and environmental costs posed by invasive species, Canada is only now beginning to develop strategies and legislation to prevent or control their impact. In contrast, the US has made a much greater effort to develop appropriate policies and legislation pertaining to the spread of invasive species (Table 2). In Canada, the closest legal definition of an invasive alien is that based on the United Nations Convention on Biological Diversity, which was adopted by the Canadian government and outlined in the Canadian Biodiversity Strategy, which was created as a result of Canada's obligation after ratification of the Convention at the Earth Summit in 1992 (Canadian Biodiversity Strategy, 1995).

The issue with invasive species and legislation in Canada and the US is not so much on how 'invasive' is defined, but more on the lack of enforcement of existing legislation and policy as well as the lack of action taken to remedy this problem. Although efforts have been made to address invasive species through legislation and policies, the Canadian government has acknowledged in internal reviews that these efforts have not been comprehensive enough to address all invasive species (Commissioner of the Environment and Sustainable Development, 2002; Standing Committee on Fisheries and Oceans, 2003). Progress in Canada has been extremely slow, in part because there is a bias towards continuous dialogue and consensus building across the country. Although this has led to some agreements, commitments and strategies, there has been a lack of real action to prevent or control invasive species (Commissioner of the Environment and Sustainable Development, 2002). Furthermore, Canada has yet to complete a national action plan to guide policy, identify threats, evaluate progress or agree on what will be done and by whom. American policy and legislation are more advanced than Canada's, especially with respect to ballast water management in the Great Lakes (see US National Aquatic Invasive Species Act (NAISA), Table 2). However, invasive species are addressed in bi-national agreements for the management of water bodies that straddle the Canada–US border, and joint institutions such as the International Joint Commission and the Great Lakes Fishery Commission. Nevertheless, legislation and policy in Canada and the US are fragmented at all levels because there is no consensus on priorities or agreement of responsibilities. This may be one of the major impediments to controlling and preventing species introductions in North America, especially in the Great Lakes.

Perspectives

The increased interest in non-native species has led to national and international initiatives to assess the risk of future introductions, the potential for establishment and expansion, and of subsequent impacts (e.g. IUCN, 1987; FAO, 1995, 1996; US ANS Task Force, 1996; NZ MAF, 2002; UK Defra, 2003). However, the development and application of non-native risk and impact assessment draws attention to two issues. Firstly, it is better to prevent introductions than to try and eradicate the species or mitigate the consequences. Secondly, the lack of clarity in our perception of what is a non-native species (Manchester and Bullock, 2000; Rahel, 2000) – in other words, which species should be assessed? The answer to this question must be guided by more than merely biogeographical and ecological issues because socioeconomic and political issues can exert an influence on what is perceived legally as 'native', 'non-native', or any intermediate status (e.g. 'naturalized' or 'acclimatized'). Indeed, the pattern of relatively unrestricted introductions of commercially important species, which seems to be common to many the countries considered here, emphasizes this point. At the same time, a multitude of terms have been used in reference to non-native species, creating much confusion and misunderstanding, which is compounded by the distinctly 'political' basis used when compiling lists of species that are native or non-native to a country. Political (country) boundaries often do not coincide with biogeographical barriers, and this leads to a lack of clarity as regards 'nativeness'.

Some obvious questions arise in this debate: Are non-native fish species those introduced by humans, irrespective of the date of introduction? Or are they those introduced after a given date? The British Ornithological Union (BOU, 2004) has taken such a line to assist the protection of birds under national wildlife legislation, especially of naturalized species. The 'British List' (BOU, 2004) categorizes bird species according to their status as of a fixed date. Category A includes species that have been recorded in an apparently natural state at least once since 1 January 1950. Category B includes species no longer present (i.e. recorded in an apparently natural state at least once up to 31 December 1949, but not recorded subsequently). Category C includes five sub-categories for naturalized species (including feral, vagrant and re-introduced) as those originally introduced by man (either deliberately or accidentally), and having established self-sustaining populations derived from the introduced stock. Two further categories include: D – species not officially on the list (in categories A or B) because of uncertainty that they ever occurred in a natural state, and E – those recorded as introductions, transportees or escapees from captivity for whom breeding populations (if any) are thought not to be self-sustaining.

In other words, for historical purposes can self-sustaining species, i.e. 'acclimatized' as part of the national fish fauna (Wheeler, 1991) such as the common carp, be viewed as 'pseudo-native', given that they have inhabited many recipient countries for a number of centuries? Or does one take a purely biogeographical point of view and consider all fish species found outside their natural range following the last ice age as warranting control and eradication? Is it desirable to concentrate legislative, regulatory and policing efforts on established species, which are virtually impossible to eradicate in most freshwater and marine systems (Smith et al., 1999)? Or would it be more appropriate in cost–benefit terms to accept existing established non-native species as part of the native fauna and concentrate efforts on inhibiting the importation of any new alien species? And in doing so, should a broader continental perspective be taken with regards species conservation, with Red Data-listed species afforded conservation protection, regardless of whether they are non-native to the country, if they are native to somewhere on that continent?

Chadd (2004) suggests that criteria are needed to define undesirable vs tolerated (or even protected) species. Examples in UK for undesirable fish are topmouth gudgeon and sunbleak, tolerated species might include carp, pumpkinseed, European catfish and rainbow trout, and protected species might even include bitterling and sunbleak, which are said to be threatened in parts of their native range. For example, the bitterling does not attract the same attention from government agencies as some other long-established non-native fishes (e.g. pumpkinseed, European catfish, pikeperch), and research in the UK has even been carried out under a conservation premise (e.g. Reynolds and Guillaume, 1998). Why the different treatment of bitterling? This remains unknown, but perhaps derives from the species' symbiotic relationship with swan mussels, which are indicators of good water quality. In taking this line of reasoning, one might suggest that introduced species that have not, or no longer, pose a threat to the recipient host ecosystem (i.e. they are essentially existing in balance with the host ecosystem) may be considered as 'naturalized'. Thus, it should be relatively easy to identify those species that need no longer be treated as aliens, with the level of intervention determined by measurable threats (to biodiversity or ecological stability) rather than some nebulous bio-taxonomic criterion. This line of reasoning, however, ignores the potential risks associated with introduced species that undertake an extended 'lag-phase' prior to being invasive (Crooks and Soule, 1999), for example following a climatic or other fluctuations in condition.

The status of non-native species remains unclear in the forthcoming European Water Framework Directive (EWFD), with some suggestions that their presence could prevent a hydrosystem from achieving a 'very good' ecological quality rating. However, in the recently proposed European Index of Biotic Integrity developed by the EC project FAME, the impairment of a river system was found to be best assessed by using all fish species present (Schmutz et al., 2004). Whereas, attempts to eradicate non-native freshwater fishes could be viewed as advantageous from both an environmental management perspective and a 'purist' biogeographical point of view, eradication of fish from open waters is at best difficult and expensive, and in many cases impossible. Furthermore, one might end up doing more harm than good in the attempt to re-establish a bygone community composition (and indeed ecosystem successional state). In fact, non-native species can occur in aquatic ecosystems otherwise considered minimally disturbed (in terms of other abiotic and biotic components). Recognition of such 'naturalized' species as part of the 'indigenous' fauna or flora would thus no longer suggest that a hydrosystem of otherwise 'good' quality is anything less than that status. The definition of terms and the essence of 'being' are, therefore, central to the debate surrounding what are and what are not non-native species (e.g. Colautti and MacIsaac, 2004), and what are the risks and impacts associated with them.

This pragmatic approach could be viewed as sensible for existing non-native species, but what of those not yet found in the wild (or even legally imported). Smith et al. (1999; p. 95) suggests that 'under certain circumstances, governments may be better advised to focus on assessing the risk posed by casuals [occasional, non-reproducing non-native] and naturalized species, and eradicating them where feasible, than trying to predict pest status at the importation stage'. Not every alien or non-native species is invasive. However, some authors regard the terms 'invasive' and 'alien' as synonymous, whereas others share the opinion that the main criterion in determining 'invasiveness' is whether the species has undergone 'naturalization', 'successful establishment', or is dispersing into new ecosystems (natural, disturbed natural, semi-natural or man-made). 'Alien' and 'invasive' are often combined as 'alien invasive species', and systematic use of 'alien invasive species', as promulgated in some government documents (e.g. UK Defra, 2003), carries with it two pitfalls. First, it re-enforces the false premise that all 'alien species' are 'invasive', which is clearly not the case. Secondly, it introduces ambiguity into any legal or policy documentation that makes systematic use of this term – these documents could be construed as being relevant to the 'invasive' species only and not all alien species.

In conclusion, two main perspectives (amongst many) can be distinguished in the relation between humans and nature as a whole, to ecosystems and species. The first aspect is essentially ethical, i.e. humans have no right to interfere in animal and plant life, destroy or remodel communities, or exterminate species. The renaissance of this approach is the appearance and development of the biological diversity concept. The second, most conspicuous aspect is practical. Humans have long been using plants, animals and objects of non-living nature for utilitarian purposes whilst modifying and destroying what it regards as unnecessary or harmful. In Russia, during the so-called Soviet period, there was a very popular slogan 'We cannot wait for benefits from nature, our task is to take those benefits'. Even though we condemn such an approach in its exaggerated form, it would be extremely naïve to state that humans should give up the exploitation of natural resources, the cultivation of food, the use of abiotic natural resources or the release of technogenic products for the sake of the conservation of 'natural' biodiversity. So, judgement of the balance between invasion and biological diversity as well as the economic and social consequences of invasion cannot be considered unequivocally in terms of 'bad' or 'good', and we are still left with the problem selecting criteria with which to assess the positive and negative consequences of non-native species invasions.

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