Chapter 6
Alien Invertebrates and Fish in European Inland Waters

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6.1 The Vulnerability of Inland Waters to Alien Species

It seems axiomatic that rivers, lakes, freshwater marshes, and other inland wetlands have an infinite value to humankind. They contribute for 20% (about US$6.6 trillion) to the estimated annual global value of the entire biosphere (Costanza et al. 1997). High-quality water has also become a strategic factor that allows for the viability and development of an increasing number of countries affected by both climate change and rising water-demand. All this justifies the current concern about the degradation of freshwater systems leading to rapid extinctions of organisms – in some cases even matching the declines recorded in tropical forests (Ricciardi and Rasmussen 1999).

There is general consensus today that some alien species will continue to be major drivers of degradation and loss of aquatic systems (Sala et al. 2000; Millennium Ecosystem Assessment 2005). The vulnerability of inland waters to bioinvasions is due to several factors (Gherardi 2007a), including the higher intrinsic dispersal ability of freshwater species compared with terrestrial organisms (Beisel 2001) and the strong impact of both human disturbance (Ross et al. 2001) and altered seasonal temperature regimes (Eaton and Scheller 1996). Species introduction into inland waters is associated with the intensity with which humans utilise these systems for recreation, food sources, and commerce (Rahel 2000), being a direct consequence of economic activity and trade globalization that benefit millions worldwide (Lodge and Shrader-Frechette 2003). This situation has generated a conflict between two often competing goals – increasing economic activity and protecting the environment, which makes it difficult to decision-makers to develop policies aimed at containing the spread of aliens and mitigating the ecological risks they pose (Gherardi 2007a).

6.2 Diversity of Animal Alien Species in European Inland Waters

European inland waters have been affected since centuries by a high rate of colonization by animal alien species. From the DAISIE database, integrated with the data collected by the IMPASSE consortium (www.hull.ac.uk/hifi/IMPASSE/), we extracted a total of 296 and 136 invertebrate and fish species alien to the entire Europe and alien to at least one European country but native to others, respectively (Fig. 6.1). Species of unknown origin which cannot be ascribed as being native or alien have been excluded from the analysis. A large component comprises chordates (mainly bony fishes) and crustaceans, whereas molluscs, flatworms, and segmented worms are less well represented. These numbers certainly underestimate the effective diversity of animal aliens in European inland waters. In fact, notwithstanding the increased scientific interest for biological invasions in the last decade and the surge of research focused on the identification of alien species in fresh waters (Gherardi 2007b), there is still a gap in knowledge regarding invertebrate taxa. On the other hand some taxa, such as fishes, have attracted the most scientific attention due their higher visibility and greater economic importance. Additionally, the area of origin of some species is still unknown. Finally, human-aided movement of species is a more widespread phenomenon if we count the many translocation events between geographically distinct drainage basins within each country. For instance, through human intervention several species endemic to northern Italy (e.g., *Alburnus arborella*, *Cobitis taenia*, and *Chondrostoma genei*) have achieved a nearly pan-Italian distribution (Bianco 1998).

The majority of animal alien species originates from Asia, the others from the Americas (in particular North America), Africa, and Oceania (Fig. 6.2). Of the 36

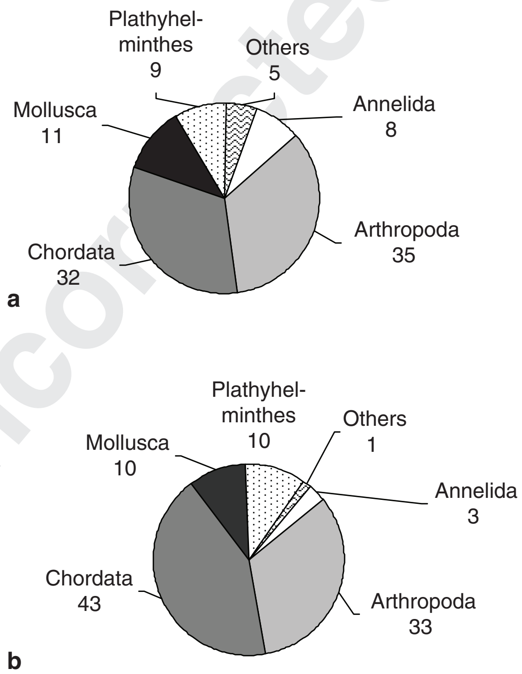

Fig. 6.1 Percentage per taxon of animal alien species recorded in European inland waters, distinguished between species (n = 296) alien to entire Europe (**a**) and species (n = 136) alien to at least one European country but native to others (**b**)

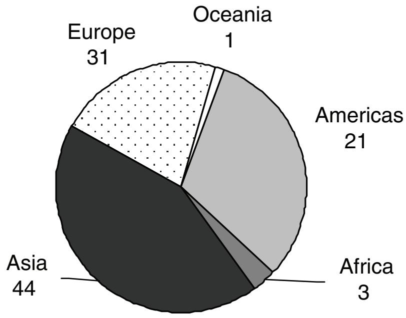

Fig. 6.2 Percentage distribution of animal alien species recorded in European inland waters per donor continent (n = 434). Species whose native range includes two or more continents were tallied more than once

European countries here examined, 19 bony fish species were recorded from 10 or more countries, such as the rainbow trout *Oncorhynchus mykiss* (31 countries), the grass carp *Ctenopharyngodon idella* (27 countries), and the brook trout ***Salvelinus fontinalis*** (26 countries). Among the other taxa, the signal crayfish *Pacifastacus leniusculus* was recorded from 25 countries, the zebra mussel ***Dreissena polymorpha*** from 22, the gastropod *Potamopyrgus antipodarum* from 18, the nematode ***Anguillicola crassus*** from 17, the flatworm *Bdellocephala punctata* from 13, and the jellyfish *Craspedacusta sowerbyi* from 12. With two notable exceptions (***D. polymorpha*** and *C. sowerbyi*), the pan-European success of these species seems to be related to frequent "inoculations" due to angling or aquaculture interest or to their association as non-targets with some "desired" species. Their spread, thus, seems to be a function of the intensity and diversity of imports as a consequence of "propagule pressure" (Williamson 1996; Colautti and MacIsaac 2004).

No European country is immune to the colonization of animal alien species but their diversity varies widely across Europe, ranging from four in Island to 129 in Ukraine. On the one hand, this large variance can be an artifact due to the diverse level of knowledge and of field survey efforts across countries. On the other hand, countries may differ for the extension of their basins (e.g., Malta vs. Germany) and for their exposure to species introductions due to their reciprocal connectivity/isolation, the presence/absence of harbors subject to intercontinental traffic, or the intensity of voluntary introductions of species due to sport and commercial fisheries or aquaculture (e.g., Italy, the Iberian Peninsula, and British Isles).

6.3 The Long History of Species Introduction

Human modifications of freshwater systems through species introduction have a long history in Europe, starting well before the 20th century. Not all of them have been recognised as causing harm, but some introduced species progressively integrated to become keystone species and are now protected under law. Notable examples include various species of crayfish, such as *Astacus astacus*: as reported by Linnaeus (1746: 358) and confirmed by Pontoppidan (1775: 175), the noble crayfish *Astacus astacus* seems to have been imported into Sweden from Russia by the Swedish King John III after 1568 and later into Finland (Westman 1973).

The introduction of freshwater animal alien species, mainly fishes, intensified after the mid 19th century under the promotion in Europe by some "acclimatization societies" (Copp et al. 2005). In Russia, for instance, almost 250 introductions that included 35 fish and 13 invertebrate species were annually conducted by the Russian Society of Acclimatization since 1857 (see references in Alexandrov et al. 2007). Similarly, the Society for Acclimatisation of Animals, Birds, Fishes, Insects and Vegetables, established in 1860 in Britain, was responsible for the majority of the introductions from continental Europe. These included pikeperch *Sander lucioperca* and the Danube catfish *Silurus glanis* (Lever 1977). In Germany, fish importations, pioneered by Max von dem Borne (1826–1894), commenced in 1882 with the introduction of North American species (e.g., ***Salvelinus fontinalis***, *Ameiurus nebulosus*, and *Micropterus dolomieu*). In Italy, the introduction of alien fishes, in particular North American species (e.g., *M. dolomieu*, *Ameiurus melas*, *Ictalurus punctatus*, and *Salvelinus namaycush*), began in the mid-19th century with most being introduced during 1897–1898 by two centers of ichthyology based in Brescia and Rome (Bianco 1998). The main motivation for these introductions was to increase the supply and diversity of aquatic food and game resources, both through natural production and in the then recently developed field of fish husbandry (Copp et al. 2005) adopting new fish hatchery techniques (Wilkins 1989). The novelty and ornamental value of the new species also played a role, as explicitly stated in the aims of the UK Acclimatisation Society ("The introduction, acclimatisation, and domestication of all noxious animals, birds, fishes, insects, and vegetables, whether useful or ornamental"; Lever 1977).

During the 20th century, the overall number of animal alien species arriving in European inland waters greatly increased (Fig. 6.3). This "explosion" (in the sense of Elton 1958) of alien crustaceans and fishes, particularly evident after the 1940s, was likely fostered by the greater mobility and trade following the Second World War.

6.4 Pathways of Introductions

A wide range of human activities became responsible for animal alien species expansion arising from extensive fish culture and sport fishing (30%) and intensive aquaculture (27%), followed by the passive transportation by vessels (25%), ornamental use (with introduction to lakes on private estates, small garden ponds, and indoor aquaria; 9%) and dispersal through canals (8%) (Fig. 6.4a). The only species to be imported for biological control were *Gambusia* spp. (1%); the eastern mosquitofish *G. holbrooki*, for instance, was introduced to Spain in 1920, Germany in

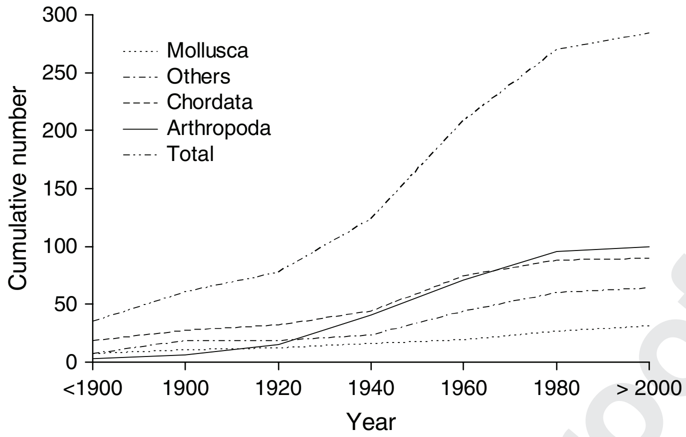

Fig. 6.3 Increase with time in the frequency of the animal alien species in European inland waters. Dates refer to the exact or approximate year of introduction into the wild or, when this datum is absent, to the year of the first record in the published literature. The date is missing for 22 species

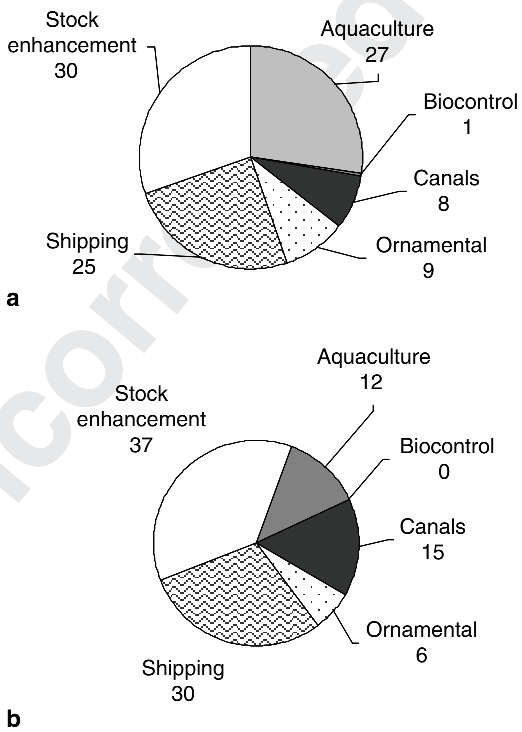

Fig. 6.4 Percentage of pathways of introduction of animal alien species in European inland waters, distinguished between species (n = 262) alien to the entire Europe (a) and species (105) alien to at least one European country but native to others (b). Species that show two or more pathways of introduction have been tallied more than once

1921, Italy in 1922 (imported from Spain) and has since then spread to many warm-water systems (Copp et al. 2005).

The role that the diverse pathways have had in introducing species from one European country to the others seems to be different (Fig. 6.4b). The importance of transportation through vessels and dispersal through canals is obviously higher (30% and 15%, respectively), whereas the frequency of escapes from aquaculture (12%) decreases and the effect of stock enhancement and ornamental use remains unchanged (37% and 6%, respectively). However, a realistic assessment of the diverse pathways of species introduction should be made on a case-by-case basis. For instance, in Germany the most frequent pathways involve the gradual incremental spread of generations through artificial canals that act as corridors (Gollasch and Nehring 2006). More direct arrivals took place as stowaways on or in the hulls of ships (Gollasch 2007), which seems to be less important in Italy (the Alps impede the construction of canals and navigation from the ports in the Mediterranean to inland waters is scarce). Motives may also vary between countries for each single species. For instance, as reported by Copp et al. (2005), the introduction of pumpkinseed (*Lepomis gibbosus*) in the late 19th and early 20th century resulted from deliberate releases for angling in France (e.g., Künstler 1908) but as escapes of ornamental fish in England (Copp et al. 2002), Slovenia (Povž and Šumer 2005), and Spain (García-Berthou and Moreno-Amich 2000).

Many introductions of animal alien species were intended for the development of fisheries and for angling via stock enhancement. The stocking of new species was a common practice in Europe in the 1960s and 1970s. This was aimed at promoting fishery diversity to counterbalance the perceived decline in the status of many fisheries (Welcomme 1988) and was accompanied by the introduction of large quantities of crustaceans, in particular amphipods (e.g., *Gammarus tigrinus*, *G. pulex*, *Pontogammarus robustoides*, *Obesogammarus crassus*, and *Echinogammarus ischnus*; Jąz̆dz̆ewski 1980), to increase commercial fish production. Several introduced species were contaminants of licensed fish consignments (e.g., top-mouth gudgeon, accidentally imported from Asia in 1960 to a pond in Romania along with a deliberate introduction of young of Chinese carp; Bănărescu 1964) or as parasites of the target species (e.g., the Plathyhelminthes ***Gyrodactylus salaris***). In the European part of the former USSR (presently Belarus, Estonia, Latvia, Lithuania, Moldova, Russia, and Ukraine), fish release (under the historical term of "acclimatization") were even "tasks from government" in annual and 5-year Soviet State Plans that had the character of state laws; large quantities of crustaceans from the Ponto-Caspian region were also moved during 1940–1970, as live food for commercial fish species (nine species of Mysidacea, seven species of Cumacea, and 17 species of Amphipoda; Karpevich 1975). Since those times, several fish species have been illegally introduced to increase the diversity of the target species for anglers (e.g., large fish species, such as *Silurus glanis*) and others have been released as bait and forage fishes (e.g., the bleak *Alburnus alburnus* in the Iberian Peninsula; Elvira and Almodóvar 2001). Most planned introductions were conducted without any scientific basis. In the Iberian Peninsula, apparent "vacant niches" were filled by stocking piscivorous fish, such as *Esox lucius*, into newly constructed reservoirs (Godinho et al. 1998). Some introductions were aimed at alleviating poverty in lowly developed areas, e.g., the red swamp crayfish, ***Procambarus clarkii***, released in the rice fields of Andalusia, Spain (Gherardi 2006). Unfortunately, several of these attempts to reduce societal problems have had unexpected negative consequences, ultimately causing more problems than they have solved (the "Frankenstein effect"; Moyle et al. 1986).

The diversification of the ornamental fish trade has been responsible for the appearance in the wild of an increasing number of aliens, either fishes (e.g., the North American fathead minnow *Pimephales promelas*, first recorded to reproduce in small enclosed private waters of the UK; Copp et al. 2007) or some molluscs used to clean aquaria by the scraping of their radula (e.g., *Melanoides tuberculata*; Cianfanelli et al. 2007). The impact of ornamental species on freshwater communities is confirmed by recent reports of the parthenogenetic marbled crayfish (*Procambarus* sp.) in the wild in Germany and the Netherlands (Souty-Grosset et al. 2006), and of *Ameiurus catus* (Britton and Davies 2006) and *Aristichthys nobilis* (Britton and Davies 2007) in Britain.

Finally, the interconnection of river basins by means of canals has facilitated the range expansion of many species within Europe either or both aided by active movement or by ship transport (e.g., Jązdżewski 1980; Bij de Vaate et al. 2002; Galil et al. 2007; Panov et al. 2007a). Numerous canals have been constructed during the last two centuries in Europe to promote trade, forming complex European networks of inland waterways which connect 37 countries in Europe and beyond (Galil et al. 2007): in Germany alone there are 1,770 km of inland waterways (Tittizer 1996). Several studies showed the penetration of Ponto-Caspian species via three important canal corridors spreading either actively or passively throughout Europe (Bij de Vaate et al. 2002; Ketelaars 2004; Galil et al. 2007). Transmission via the northern corridor involved the zebra mussel ***Dreissena polymorpha*** and the cladocerans ***Cercopagis pengoi***, *Evadne anonyx*, and *Cornigerius maeoticus* (Panov et al. 2007b), the central corridor the amphipod *Chelicorophium curvispinum*, and the southern corridor the amphipod ***Dikerogammarus villosus***, isopod *Jaera istri*, mysid *Limnomysis benedeni*, and the polychaete *Hypania invalida* (Bij de Vaate et al. 2002). The arrival of Ponto-Caspian species such as ***Dreissena polymorpha*** and ***Cercopagis pengoi*** at the main harbors of the North and the Baltic Seas was followed by their "jump" in ballast to the Laurentian Great Lakes (MacIsaac et al. 2001; Panov et al. 2007b).

6.5 The Multilevel Impact of Freshwater Animal Alien Species

Not all alien species can be considered to have negative impacts; in fact some of them are universally recognised as being of benefit (Ewel et al. 1999). Also among those species that have been introduced by humans and were able to form self-sustaining populations, as many as 80–90% (Williamson 1996) – or less than 75%, at least for some taxa (Jerscke and Strayer 2005) – may actually have minimal detectable effects on the environment. So, the fraction of aliens that yield problems may be small, but although few species they have had catastrophic impacts on the environment and human economy. For some (but not all) species recorded the multilevel impact (Parker et al. 1999) on the recipient communities and ecosystems is known, even if seldom quantified (Gherardi 2007b), and include (1) competitive superiority over native species, possibly leading to extinction, e.g., ***Dikerogammarus villosus*** (Dick and Platvoet 2000); (2) hybridization with native species with the consequent reduction of genetic diversity, e.g., *Carassius auratus* and *C. carpio* (Hänfling et al. 2005); (3) disruption of the pristine interactions between species and of the existing food web links, rainbow trout (*O. mykiss*) (Nyström et al. 2001) and *Pacifastacus leniusculus* (Nyström 1999); (4) habitat modification and changes to ecosystem functioning, e.g., ***Procambarus clarkii*** (Gherardi 2007b) and *Chelicorophium curvispinum* (Devin et al. 2005); (5) transmission of parasites and diseases, e.g., ***Anguillicola crassus*** (Kirk 2003) and ***Pseudorasbora parva*** (Gozlan et al. 2005); and (6) damages to socio-economics, recreation, human health and well-being, e.g., ***Dreissena polymorpha*** (Karatayev et al. 1997). Conversely, we are still ignorant about the long-term ecological and evolutionary feedbacks between invasive species and the invaded communities and ecosystems (Strayer et al. 2006).

At the river basin level, some animal aliens have dominated aquatic communities, as in the case of the red swamp crayfish in southern Europe (Gherardi 2006). Large catchments may function as hotspots of alien diversity. For instance, in the River Rhine, more than 95% of macroinvertebrates consists of aliens (Bij de Vaate et al. 2002). These will have originated from different biogeographic regions (North America, e.g., *Gammarus tigrinus* and *Orconectes limosus*, Mediterranean, the freshwater shrimp *Atyaephyra desmaresti*, and Ponto-Caspian region, e.g., *Gammarus roeseli* and ***Dikerogammarus villosus***; Beisel 2001). Biotic homogenization among basins, defined as the ecological process by which formerly disparate biota lose biological distinctiveness at any level of organization (McKinney and Lockwood 1999), has evolved as the results of global alien species spread and the extinction of endemic species. The fish fauna in the Iberian Peninsula, for instance, showed in 2001 an increased similarity of over 17% from the original pristine situation (Clavero and Garcia-Berthou 2006). Similar processes are taking place elsewhere in Europe, although their quantification is still missing.

6.6 Concluding Remarks

Several animal aliens are today affecting freshwater communities, imperiling native species, altering ecosystem processes, and causing damage to human endeavors. Recognizing these threats certainly lays the strongest and possibly the only ethical basis for the concern that scientists, laypeople, and institutions have today about the problem of introduced species (Simberloff 2003). This general awareness of the detrimental effects of aliens is in the process of being translated into implemented policies aimed at preventing new undesirable introductions (e.g., Council Regulation No 708/2007 concerning use of alien and locally absent species in aquaculture), responding quickly to newly discovered alien species, and controlling the most damaging established aliens (e.g., European Strategy on Invasive Alien Species, CEC 2002). However, despite the progress made in the last decade in the comprehension of biological invasions, current efforts on this front still suffer from a lack of basic scientific information about the extent and distribution of alien diversity, particularly in inland water systems. A much greater and more urgently applied investment to address these deficiencies is thus warranted.

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Author Queries:

[Au1]: Gherardi, 2007c is not cited.
[Au2]: Gherardi, 2007d is not cited.