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The impacts of invasive alien species in Europe

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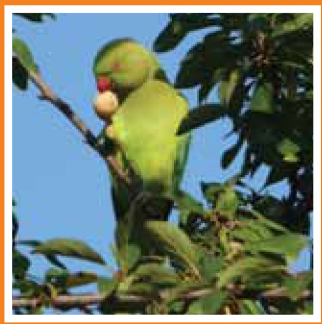

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European Environment Agency

The impacts of invasive alien species in Europe

European Environment Agency

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The authors also provided pictures and updated material for the maps.

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All maps were developed on a GIS platform by Teresa Maria Stirpe.

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Executive summary

Invasive alien species (IAS) are one of the most important direct drivers of biodiversity loss and ecosystem service changes, and constitute the greatest threat to fragile ecosystems such as islands. Although the introduction of alien species is known to bring benefits to specific sectors of society and produce high economic profit and social welfare in the short term, they may have far-reaching and harmful effects on biodiversity and natural resources for generations. IAS can also affect human life and health and cause serious economic damage to agriculture, forestry and fisheries, which is estimated to be at least EUR 12 billion per year in Europe alone.

Raising awareness of the issue and providing up-to-data scientific information is an essential requirement to achieve the EU and global 2020 biodiversity targets, particularly in the light of the current work on developing EU legislation to combat IAS. The purpose of this report is to raise awareness and inform stakeholders, decision-makers, policymakers and the general public about the environmental and socioeconomic impacts of IAS. The European Environment Agency (EEA) and the Invasive Species Specialist Group (ISSG) of the International Union for Conservation of Nature (IUCN) have therefore shared expertise in producing this joint report.

The report focuses on the multifaceted impact of IAS. Twenty-eight dedicated species accounts are provided to highlight the various types of impact — gathered together in 14 categories identified for this report — provoked by IAS, without neglecting the benefits of these species. For example, competition, predation and transmission of diseases between alien and native species are frequent and can pose a major threat to native species, as exemplified by the case studies relative to the brook trout, the red-swamp crayfish, the bullfrog and the pathogenic chytrid fungus. Hybridisation between alien and native species may represent a major threat in various ways, as shown by the renowned case of the ruddy duck.

Alien species may also affect ecosystem services, which in turn can have an impact on human well-being. Some IAS might have an impact on a specific ecosystem service, as in the case of the Spanish slug, which affects provisioning ecosystem services, as it feeds on horticultural plants. Other IAS may affect multiple ecosystem services, as in the case of the Japanese knotweed and the ice plant, as they may profoundly change ecosystem functioning by altering species composition, physical habitat components, nutrient cycling, primary production, etc. There are also IAS acting as vectors of disease (like the Asian tiger mosquito) and affecting human health (like the common ragweed), as well as IAS causing extensive damage to infrastructures (e.g. the zebra mussels), landscape (red palm weevil) and agriculture (grey squirrel).

Scenarios show that with the increasing trends in the global movement of people and goods, the number and impact of harmful IAS in Europe may grow significantly in the future. In addition, climate change may produce new opportunities for IAS to proliferate and spread. In this situation some IAS might initiate complex, unpredictable cascades of effects.

The best way to deal with the threat of IAS to biodiversity and society is through a combination of preventive measures, early detection and rapid response to new incursions, with permanent management only as the last option. Unfortunately, so far, due to a lack of information and awareness, and in the absence of comprehensive and harmonised legislation at the European level, the issue of IAS and their impact has often been underestimated. As such, the EEA and ISSG have an important role to play in developing and circulating the required knowledge base on IAS impact to promote and support the framing and implementation of adequate prevention and mitigation measures.

1 Introduction

IAS are one of the most important direct drivers of biodiversity loss and ecosystem service changes, and they constitute the greatest threat to fragile ecosystems such as islands. In the last four centuries IAS have been one of the key factors threatening biodiversity, with the percentage of threatened species impacted by IAS ranging from 33 % for birds and 11 % for amphibians (Vié et al., 2008). For 170 out of the 680 known animal extinctions for which we know the causes of extinction, 54 % included the effects of IAS, and for one out of five (20 %) IAS were the only cited cause of extinction (Clavero and García-Berthou, 2005). In economic terms, the annual losses caused by IAS in Australia, Brazil, India, South Africa, the United Kingdom and the United States have been calculated in the range of USD 300 billion per year (Pimentel et al., 2001; 2005). In Europe alone, the economic costs of biological invasions are estimated to be at least EUR 12 billion per year (Kettunen et al., 2009).

The damage caused by the introduction of IAS has been known for millennia in Europe. Pliny the Elder, an erudite natural philosopher and encyclopaedist of the early Roman Empire, wrote in his *Natural History* (77 AD) that the invasion of **rabbit** ([1]) in the Balearic Islands was such a severe problem that the help of the late Emperor Augustus and the Roman troops was sought to control them. Introductions of rabbit, a native to the southern Iberian Peninsula, had probably been started in other European countries by ancient Romans. Since then this has taken place in many regions of the world, resulting in a significant impact on the environment and socio-economy alike. Ancient Romans were not the first people contributing to the spread of IAS in Europe; some introductions are known to date back to at least the Neolithic Age, especially in the Mediterranean region. Many of these species have now become an integral part of our landscapes and cultures, as in the case of the Mediterranean cypress in Tuscany or the pheasant in many areas of Europe.

Another effect of the long history of species introductions occurring in Europe is that the level of awareness of the IAS problem is much lower compared to other parts of the world. Apparently Europeans have grown accustomed to alien species, and this may explain the extremely high patterns of invasions recorded in our region both on Europe's mainland and in the marine environment. In recent decades the rate of new introductions to Europe has accelerated and is still increasing for all groups except mammals. As a result of the introductions carried out for centuries, today over 10 000 alien species are present in Europe.

Because of the increasing impacts recorded in Europe as well as globally, the concern regarding this threat is indeed raising. This change of attitude is also the consequence of the adverse impacts IAS have not only on biodiversity, but also on human life

What is an alien species?

An alien species is an organism introduced outside its natural past or present distribution range by human agency, either directly or indirectly. This definition implies an active movement facilitated by humans through a number of different pathways, and covers both intentional and unintentional movements of species. Introductions can in fact be intentional — as in the case of species released to the environment for hunting, angling, aquaculture, forestry, agriculture, horticulture and gardening — and accidental, as in the case of hitchhikers or stowaways, or aquatic species transported through ballast water. Those alien species which cause negative impacts on biodiversity, socio-economy or human health are considered as invasive (CBD, 2002).

([1]) For a list of all scientific names of the species mentioned in the report, please see Annex 1. In bold in the text are the species described in the species accounts (see Table 3.1).

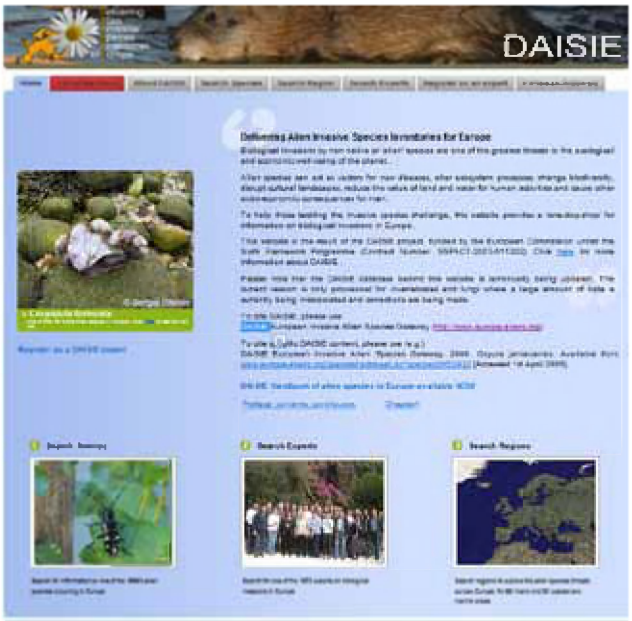
The rabbit is a key driver of ecosystem change in its introduced range, as it can cause extensive erosion of soils by overgrazing and burrowing which in turn can cause significant impact on native communities.

© Photo courtesy of Keith Springer

and health, because they could affect our well-being and may cause serious economic damage, for example to agriculture, forestry and fisheries. Once IAS have established, they can be hard or even impossible to eradicate, resulting in an irreversible impact on local species and habitats. Furthermore, biological invasions are a growing driver of change and — together with climate change — one of the most difficult to reverse.

In recent times the true extent of the pervasive threat posed by IAS in terms of both ecological and socio-economic impacts has become much better understood. Scientific researches focusing on the impact of IAS on the environment and human well-being have recently been published, including many detailed technical reports made ad hoc for the European Commission. For example, these researches show that of the 395 European native species listed as critically endangered by the IUCN Red List of Threatened Species, 110 are in danger because of IAS (IUCN, 2011). Of the over 10 000 species introduced to Europe, whilst most of them do not cause any problem, at least 15 % are known to have a negative ecological or economic impact. This percentage may even be an underestimation, as the lack of knowledge on the impacts of many alien species could be misleading. The actual number of harmful species might be higher than 15 %, and is likely to increase with the acquisition of new knowledge on species not yet sufficiently studied.

The introduction of alien species is also known to bring enormous benefits to specific sectors. Humans depend heavily on several non-indigenous organisms, for example when they are used for agriculture, animal farming, fishery, wood production, medicine, aesthetic enjoyment, hunting or trade of ornamental plants. It has been suggested that in some cases alien species can have a positive role on the natural environment, for example when they represent a basic food resource for native species, or when they replace some vegetation cover that had been previously destroyed. However these conclusions should be considered with extreme care, as in most cases — if not all — the beneficial effects can still lead to long-term harm to the natural ecosystems. Often, pros and cons are assessed in different currencies and time-scales, therefore comparisons can sometimes be awkward and misleading. While alien species can produce



A major source of information on over 10 000 alien species in Europe and their impact is the Delivering Alien Invasive Species Inventory for Europe (DAISIE) — European Invasive Alien Species Gateway (http://www.europe-aliens.org).

high economic profit and social welfare in the short term, they may harm biodiversity and natural resources for subsequent generations. There is considerable lack of knowledge with regard to understanding the negative long-term effects of biological invasions.

The spread of invasive alien animal and plant species is thus among the most urgent nature conservation issues to be faced, together with habitat destruction and fragmentation, at both the European and global levels. According to the recent Communication of *Our life insurance, our natural capital: an EU biodiversity strategy to 2020* (COM (2011) 244 final), the European Commission has committed that 'By 2020, Invasive Alien Species (IAS) and their pathways are identified and prioritised, priority species are controlled or eradicated, and pathways are managed to prevent the introduction and establishment of new IAS' (see Target 5: Combat Invasive Alien Species). Additionally, in relation to Action 16 (Establish a dedicated instrument on Invasive Alien Species), 'The Commission will fill policy gaps in combating IAS by developing a dedicated legislative instrument by 2012.' This approach is perfectly in line with Aichi Target 9 of the Strategic Plan for biodiversity 2011–2020, adopted during the 10th meeting of the Conference of the Parties of the Convention on Biological Diversity (CBD COP10, which took place in Nagoya, Aichi Prefecture, Japan, in October 2010).

The role of the EEA

The EEA contributed to the work of the European Commission with the technical report *Towards an early warning and information system for invasive alien species (IAS) threatening biodiversity in Europe* aimed at assessing the options for a European early warning system, identifying key challenges and presenting cost estimates for different institutional managements. In the last years, the EEA invested further considerable resources in addressing IAS also within other initiatives, such as the 'Streamlining European 2010 Biodiversity Indicators' (SEBI 2010) project, a process to select and streamline a set of biodiversity indicators to assess progress towards the European target of halting biodiversity loss by 2010. As part of this process, an expert group on trends in IAS in Europe was set up to develop specific indicators (i.e. the two elements currently included are 'Cumulative number of alien species in Europe since 1900' and 'Worst invasive alien species threatening biodiversity in Europe').

In this context the present report is aimed at raising awareness and informing on the environmental and socio-economic impact of IAS, not only for all stakeholders and the general public but also decision-makers and policymakers. In fact, the biodiversity strategy needs to be aligned with the biodiversity knowledge base to underpin policy with up-to-date scientific data and information. For this purpose a selection of IAS of special conservation concern has been analysed with the objective to describe and highlight the main negative impacts provoked by biological invasions, without neglecting benefits of these species. Hopefully this will facilitate awareness of all stakeholders, which is an essential requirement to achieve the aforementioned EU and global 2020 biodiversity targets.

EU Biodiversity Strategy to 2020, Target 5 and Convention on Biological Diversity Aichi Biodiversity, Target 9

By 2020, Invasive Alien Species and their pathways are identified and prioritised, priority species are controlled or eradicated, and pathways are managed to prevent the introduction and establishment of new IAS.

2 The multifaceted impact of IAS in Europe and the world

Many species are introduced to areas outside of their natural range, and are hence non-native, but not all of these will become invasive. Many will not be able to adapt to the new environment at all, and may eventually die off. This is the case of the many species of crocodiles, pythons and other dangerous animals that from time to time have been released or escaped in the wild in several European countries, but which have not managed to establish self-sustaining populations. In other circumstances, some species have thrived in the wild for a while, but then failed to become naturalised. For example it is known that a small population of brown bear was established in Corsica in the Middle Age and eventually became extinct after a few centuries. Other non-native species cope well in their new surroundings without ousting native species from the ecosystem, co-existing without competition. Sometimes such species are granted a permanent 'residence permit' as in the case of species introduced in ancient times which have now become part of our natural and cultural heritage. In Corsica and Sardinia, for example, all terrestrial mammals are considered introduced by human agency. Some of them, like the Corsican deer and the mouflon, in light of their conservation/historical value are even protected by EU legislation, i.e. the Habitats Directive. This shows how the presence of some alien species, especially those introduced in ancient times, is not only tolerated in Europe but even facilitated when it does not negatively affect the environment or the well-being of people.

An ecosystem can support these changes as long as all the original key components are not negatively affected. What causes a species to be labelled as invasive rather than simply non-native is its ability to harm native species through competition and predation, or by transferring pathogens and parasites, or through hybridisation. All these interactions might have an impact on the biological diversity of the region and possibly on the livelihoods of human communities. Thus, it is important to distinguish between alien species in general — which are introduced outside their natural range by humans, but which in many cases are harmless — and IAS, which by definition not only are introduced outside their range but also cause substantial harm to biodiversity and human livelihood. IAS, not alien species, are indeed a major cause of concern for the impact they have on biodiversity and human well-being.

In the past the general public and policymakers have underestimated the importance and impact of IAS. However, many projects have been recently funded by the European Commission that contributed to increased knowledge on the topic in Europe. The (DAISIE — European Invasive Alien Species Gateway (www.europe-aliens.org) is a benchmark in this regard. DAISIE has supported the realisation of the most comprehensive review of the ecological and economic impacts caused by alien plants, vertebrates and invertebrate species in Europe, covering terrestrial, freshwater and marine environments. The analysis of data collected by DAISIE showed that at least 11 % and 13 % of European alien species are known to have negative ecological or economic impacts, respectively (Vilà et al., 2010). The data confirmed that in Europe, like in other parts of the world, biological invasions can have far-reaching and often harmful effects on biological diversity and functioning of invaded ecosystems as well as cause significant economic losses. Alien species can act as vectors for new diseases, alter ecosystem processes, reduce biodiversity, change landscapes, reduce the value of land and water for human activities, and cause other socio-economic consequences for humans. In this regard, terrestrial mammals are the group with the highest proportion of species with known impact and are responsible for the greatest range of impacts. The groups with most species causing impacts are terrestrial invertebrates and terrestrial plants. While terrestrial invertebrates create greater economic than ecological impacts, the opposite is true for terrestrial plants.

Alien species do not only have socio-economic or biologically harmful effects. They can also bring some benefits, for example timber, ornamental value or as game animals. Some analyses of ecological impacts of biological invasions have highlighted that IAS can facilitate particular native species through a number of mechanisms. Such mechanisms include the provision of supplementary food and cover resources (e.g. through habitat modification), and the release from major limiting factors, like the removal of predators or competing species. An example of an IAS that can be both beneficial and detrimental is the **red swamp crayfish**. The introduction of crayfish may be assumed to contribute positively to local economies by opening new aquaculture opportunities, e.g. in southern Spain, but it must be stressed simultaneously that North American crayfish carry the pathogen of crayfish plague that can drive native crayfish species to local extinction.

Identifying possible benefits from an alien species to some native species is very complex and generalisations may be misleading. In fact, whilst certain species — just like the red swamp crayfish — may be an important prey item on the diet of native threatened species, it is important to consider that in the absence of the alien invader, native species would have certainly relied on different food items. Thus, if a threatened native species receives benefits from an alien species, this should not be seen as a strategy for conservation purposes. In fact, the diet of many vertebrates may depend upon the alien crayfish, but this is a consequence of a completely altered structure of the invaded community and does not guarantee the conservation of intact and well structured ecosystems.

In the present report, 14 types of IAS impacts have been identified, classified into four major groups:

- impacts of IAS on biodiversity;
- impacts of IAS on ecosystem services;
- impacts of IAS on human health;
- impacts of IAS on economic activities.

2.1 Impacts of IAS on biodiversity

IAS can affect biological diversity in various ways encompassing the gene, species and ecosystem levels. Competition, predation and transmission

Feral cats have been directly responsible for the extinction of numerous species on islands worldwide, including endemic species of mammals, birds and reptiles.

of diseases between alien and native species are frequent and can pose a major threat to native species. This is particularly true on islands and isolated continental ecosystems, such as freshwaters, where IAS are known to cause cascading effects across all levels of the food web. Effects involving more than two IAS are also documented, showing how complex the interactions between alien and native species can be in the invasion process. For example, the **brook trout** may compete for food and cover with and predate on native fish such as other salmonids. This may lead to the replacement of native salmonids and in turn might negatively affect the freshwater pearl mussel, an endangered species whose biological cycle depends on them.

Similar impacts also occur in terrestrial environments. Generalist predators such as feral cats, once introduced to islands, can prey on a variety of native species, which suffer severe population declines and even face extinction. In Britain, for example, estimates derived from scaling up local studies to the national level show that cats kill 25–29 million birds per annum (Sims et al., 2008). It is easy to imagine how detrimental this species can be, considering that cats have been introduced to about 179 000 islands worldwide. According to a recent study (Medina et al., 2011), the impacts of feral cats is known from at least 120 different islands on at least 175 different species of vertebrates (25 reptiles, 123 birds, and 27 mammals), many of which are listed on the IUCN Red List. For example, in the Canary Islands (Medina et al., 2009), four species (one endemic bird — the Fuerteventura stonechat — and three endemic giant lizards) out of a total of 68 species (including invertebrates) identified as preys are considered threatened. Also, at the global level, where cats are considered responsible for at least 14 % global bird, mammal and reptile extinctions and are the principal threat to almost 8 % of critically endangered birds, mammals and reptiles, the impact on endemic species can be dramatic. In New Zealand, several islands experienced a rapid demise of the native land bird fauna due to cat predation. Stephens Island provides the classic example of the effect that predation by feral cats can have on an island land bird fauna. Here cats became established in 1894, and after increasing in numbers rapidly exterminated several other species. The flightless Stephens Island wren was only the first to disappear. With just a little more care, many islands may have remained a safe haven for many species now disappeared.

Amphibians infected by the chytrid fungus *Batrachochytrium dendrobatidis* can die because of skin lesions and dysfunctions, which may lead to a heart attack or suffocation. Sophisticated laboratory analyses are needed to diagnose chytridiomycosis. In fact, the lack of specific clinical signs (except for some 'non-specific' skin damages and/or behavioural changes) makes the diagnosis of the infection with the naked eye practically impossible. This also explains why no signs are evident in the pictures.

© Photo courtesy of Jaime Bosch

The Harlequin ladybird is highly variable in colours and patterns. It has negative impacts on biodiversity and economy.

© Photo courtesy of Wolfgang Rabitsch

The Harlequin ladybird, a species native to central and East Asia, rapidly spread over Europe after it escaped from greenhouses in 1991, where it was used as biocontrol agent. The beetle is a voracious predator of aphids and scales, but also of other insects that feed on its prey, including other ladybirds. It has adapted to a wide range of climates and habitats and has caused local declines in native ladybird diversity. When thousands of individuals aggregate for hibernation in buildings, they become a nuisance and may even disturb wine production when invading vineyards, because they cannot be separated when pressing the grapes.

The impact of emerging infectious diseases can be even more fundamental. Amphibian species worldwide are known to decline and among the reasons the **chytrid fungus** and the subsequent spread of chytridiomycosis are held responsible.

Hybridisation between alien and native species may represent a major threat in various ways, from reducing genetic variation and eroding gene pools, to introducing maladaptive genes to wild populations and resulting in more vigorous and invasive hybrids. Hybridisation has occurred between a number of species, the most famous being probably the alien **ruddy duck** and the native white-headed duck.

The Bohemian knotweed is a hybrid of the **Japanese knotweed** and giant knotweed that originated in Europe and apparently spreads faster than its alien parents in Europe.

As a major type of biodiversity impact, IAS can alter the functioning of entire ecosystems. For example, the successful competition of the alien **zebra mussel** with native clams in the freshwater ecosystem has lead to local extirpations of the native molluscs. In addition, its introduction to lakes in Europe and North America has resulted in significant changes in the water quality of the lakes. This invasive mussel may thus have the 'power' to alter the structure and function of entire ecosystems.

Another example is the tropical alga *Caulerpa taxifolia.* In thousands of hectares of the Mediterranean, this tropical Pacific alga has overgrown and substantially replaced seagrass stands dominated by *Posidonia oceanica*, causing major changes in the marine community and affecting key ecosystem function and services. In recent years, the expansion of *Caulerpa taxifolia* appears to be in recess, as opposed to that of

Caulerpa taxifolia is a tropical seaweed also known as 'killer algae' for the threat it represents to marine ecosystems.

C. racemosa which invaded the Mediterranean from the Red Sea across the Suez channel on ships' hulls or in ballast water. This new alga is spreading very rapidly and seems capable even of out-competing *Caulerpa taxifolia*. Unfortunately IAS, including a high number of fish and invertebrates, are doing great injury to the marine environments in Europe, but because their harm is affecting species and habitats hidden behind a veil of water, out of sight of most people, they escape the level of concern they deserve.

2.2 Impacts of IAS on ecosystem services

Ecosystem services (MA, 2005; EEA, 2010) are the direct and indirect contributions (benefits) of ecosystems to human well-being, and are classified in four categories:

- provisioning services;
- regulating services;
- cultural services;
- supporting (habitat) services.

Provisioning services are products obtained from ecosystems such as water, food, genetic resources, wood, fibre and medicines. Regulating services are defined as the benefits obtained from the regulation of ecosystem processes such as climate stability, natural hazard regulation (flood control), water purification and waste management, pollination or pest control. Supporting (habitat) services highlight the importance of ecosystems to ensure soil formation and nutrient cycling, but also to provide habitat for migratory species and to maintain the viability of gene pools. Cultural services include recreational, religious, spiritual and intellectual enrichment, and other non-material benefits that people obtain from ecosystems. The ecosystem services approach allows the linking of ecological and economic impacts, by assuming that the effect of any ecological change influences ecosystem processes and, in turn, human well-being.

Alien species may affect the ecosystem services mentioned above and this in turn can have an impact on human well-being. Some IAS might have an impact on a specific ecosystem service, as in the case of the **Spanish slug** (which is on provisioning ecosystem services, as it feeds on horticultural plants). However, there are IAS that may have at the same time several types of impacts not restricted to

The first specimen of black locust *Robinia pseudoacacia* introduced in Europe, in 1601 in the Jardin des Plantes, in Paris. It is thought to be have been planted by the son of Jean Robin, a major botanist at the French court, in honour of whom the species was named by Linnaeus.

© Photo courtesy of Riccardo Scalera

a single ecosystem service, as they may profoundly change the ecosystem functioning by altering species composition, physical habitat components, nutrient cycling, primary production or disturbance regimes. An example is the **zebra mussel**, which can modify supporting, regulating and, ultimately, provisioning services in aquatic ecosystems, for example through alteration of water quality and bioaccumulation. Also the **coypu** undermines riverbanks by burrowing, damages crops, and greatly disturbs riverine vegetation (and the associate fauna) by grazing.

Among plants, an example is the black locust which, as a nitrogen fixing species, can achieve early dominance on dry and open sites where nitrogen is limiting to other species, thus strongly changing species composition and affecting supporting ecosystem services. The species is however affecting ecosystem services and providing additional ones at the same time. For example, while its large root system near the surface can sometimes buckle sidewalks or interfere with mowing, it is considered very effective to stop erosion of degraded slopes. Also, although it may compete with native plants for pollinating bees, thus affecting regulating ecosystem services, this species is appreciated by some beekeepers that are willing to produce honey from its flowers.

2.3 Impacts of IAS on human health

It is well established knowledge that IAS can have a prominent impact on human health, by being specific disease vectors or by posing a direct health threat. Examples of human health problems caused by IAS include skin lesions upon contact with **giant hogweed** sap, rhino-conjunctivitis and asthma through contact with **common ragweed** allergenic pollen, eruptive dermatitis following contact with agave, or chikungunya virus spread by the **tiger mosquito**.

2.4 Impacts of IAS on economic activities

Biological invasions also cause significant impacts on a number of economic activities, for example by provoking damages to infrastructure, landscapes and agriculture. Such impacts can have strong socio-economic consequences which, however, may be difficult to quantify in monetary terms. In general, more IAS are known to cause economic than ecological impacts, because the former are more easily perceived and are immediately reported by persons concerned. Economic pests are also likely to attract more scientific attention. The **red palm weevil**, for example, is destroying large numbers of palms, thus literally changing urban landscapes, but also creating huge economic damage.

Examples of direct economic impacts include the damage caused by **Japanese knotweed** to flood defence structures and the impact of bark stripping by grey squirrels on forestry production.

The **coypu** — and the muskrat as well — damage river banks through digging and increase the risk and severity of floods in many central and southern European countries.

The **zebra mussel** can provoke a number of damages, by blocking pipes, vents and any holes or openings where water flows. This is why it is considered a major macrofoulant of power-generating plants and industrial and municipal water systems, which generates enormous costs for society and businesses. Just to give an idea of the potential extent of damage by this mollusc, in Ukraine it invaded the water cooling reservoir of the Chernobyl nuclear power plant.

Date palms dying after being attacked by the red palm weevil near Rome, Italy.

The zebra mussel can cause damage by blocking pipes, vents and any holes or openings where water flows. Reservoir tower safety grating clogged with zebra mussels (Rabisha Reservoir, Bulgaria).

In addition, there are species that are rapidly changing the original landscape of the Mediterranean region. Examples are the central American *Opuntia* and *Agave* species, which are typical floral elements and attract the attention of tourists looking for 'Wild West' landscapes.

3 The species accounts

The species accounts refer to a selection of 28 'flagship' IAS which encompass a diverse range of groups that threaten European freshwater, brackish water, marine and terrestrial environments. The species have been selected because of the significant harm they pose to biological diversity, socio-economic values and human health in Europe. The aim is to provide examples to illustrate the range of consequences of the 14 types of impact identified in this report. For each type of impact two species accounts are provided (see Table 3.1).

The key sources of information for the species accounts are the DAISIE and the European Network on Invasive Alien Species (NOBANIS) fact sheets (2). In a number of cases the fact sheets available in the Great Britain non-native species secretariat website (3) and the European and Mediterranean Plant Protection Organization (EPPO) portal (4) were also considered. In addition, a number of relevant papers and technical reports have been used (see References for the key ones used for each species). Furthermore, for some species the information reported has been validated and integrated by a number of experts who kindly provided their comments and suggestions.

The selection of species has been based on the following criteria:

- species being representative for the main taxonomic groups (vascular plants, fungi, algae, mammals, birds, reptiles, amphibians, fish, insects, molluscs, crustaceans) and all environments (terrestrial, freshwater, marine);
- species with solid data regarding the type of impact;
- species of high concern in Europe, i.e. for which the European Commission has allocated major resources to reduce their impact (e.g. ruddy duck, common ragweed, raccoon dog, giant hogweed, American mink).

Of course, the lists of both species and impacts are not intended to be comprehensive and exhaustive. Most of the selected species might be associated with more than a single type of impact (see Table 3.2), the most prominent of which might not necessarily be the one that the target species is meant to exemplify in this report.

The main sources of all maps included in the texts are reported in the relevant caption. The following types of data have been collected and gathered together to draw the maps: a) geo-referenced data; b) grid data; c) images of distribution maps; d) anecdotal descriptions of occurrences. For those based on the maps developed within DAISIE, the names of the relevant authors are indicated, together with the year and reference to the DAISIE European Invasive Alien Species Gateway (5). Since the focus of this work is not on the maps, (they are included only to provide the reader with an indication of the best knowledge on the species distribution at present), they should not be used for purposes other than information and communication. Thus their use for further scientific analysis would be not appropriate.

(2) See http://www.nobanis.org/Factsheets.asp.
(3) See http://www.nonnativespecies.org.
(4) See http://www.eppo.org.
(5) DAISIE European Invasive Alien Species Gateway, 2012, 100 of The Worst, http://www.europe-aliens.org/speciesTheWorst.do (accessed 5 March 2012).

Table 3.1 The main types of impact caused by IAS separated into 4 main categories, and the 28 'flagship' species selected to describe such impacts

Impact	Subsection	Species account
Impacts of IAS on biodiversity	Competing with local species	American mink
		Bullfrog
	Predating local species	Brook trout
		Common slider
	Transmitting or causing diseases or harm to local species	Red swamp crayfish
		Chytrid fungus
	Hybridising with native species	Canada goose
		Ruddy duck
	Affecting habitats ecosystem engineering or modifying or changing habitats	Rabbit
		Killer alga
Impacts of IAS on ecosystem services	Interfering with supporting services	Japanese knotweed
		Ice plant
	Interfering with provisioning services	Pontic rhododendron
		Spanish slug
	Interfering with regulating services	Water hyacinth
		Yellow-legged hornet
	Interfering with cultural services	Killer shrimp
		Tree of heaven
Impacts of IAS on human health	Disease vectors	Asian tiger mosquito
		Raccoon dog
	Health impacts	Common ragweed
		Giant hogweed
Impacts of IAS on economic activities	Damaging infrastructure	Coypu
		Zebra mussel
	Damaging landscapes	Red palm weevil
		Horse-chestnut leaf-miner
	Damaging agriculture	Grey squirrel
		Rose-ringed Parakeet

Table 3.2 The selected alien species and their multiple impact

	Competing with local species	Predating local species	Transmitting or causing diseases or harm to local species	Hybridising with native species	Affecting habitats	Interfering with supporting services	Interfering with provisioning services	Interfering with regulating services	Interfering with cultural services	Disease vectors	Health impacts	Damaging infrastructure	Damaging landscapes	Damaging agriculture
American mink	X	O	O				O		O	O				
Bullfrog	X	O	O											
Brook trout	O	X		O			O		O					
Common slider	O	X	O							O	O			
Red swamp crayfish	O	O	X		O	O								
Chytrid fungus			X						O					
Canada goose	O		O	X		O		O	O	O	O			O
Ruddy duck				X					O					
Rabbit	O				X			O	O				O	O
Killer alga	O				X		O	O	O				O	
Japanese knotweed	O				O	X	O	O	O			O	O	
Ice plant	O				O	X	O	O	O			O	O	
Pontic rhododendron	O				O		X	O	O				O	
Spanish slug	O	O		O	O		X		O					O
Water hyacinth	O				O	O	O	X	O			O	O	
Yellow-legged hornet	O	O	O				O	X			O			
Killer shrimp	O	O					O		X					
Tree of heaven	O				O		O	O	X		O	O	O	
Asian tiger mosquito	O								O	X				
Raccoon dog	O	O	O		O		O			X	O			O
Common ragweed	O					O	O	O	O		X		O	O
Giant hogweed	O				O			O	O		X			
Coypu	O		O		O		O	O	O	O	O	X		O
Zebra mussel	O					O	O	O	O			X	O	
Red palm weevil							O		O				X	O
Horse-chestnut leaf-miner					O			O	O				X	
Grey squirrel	O	O	O						O					X
Rose-ringed Parakeet	O		O						O					X

Note: The X indicates the impact that the relevant species is chosen to exemplify in the species account (but not necessarily the most prominent for the species, see description in the text). An O indicates other impacts that the relevant species may have.

Impacts of IAS on biodiversity — competing with local species

American mink *Neovison vison*

The American mink

Species description

The American mink is a small carnivore of the weasel family characterised by an elongated body and relatively short limbs, the size of a small cat (but males and females differ greatly in body size, as females are smaller). In wild animals the coat is usually dark brown, often with white markings on the ventral side, but many colour mutations are known in bred animals, among which black, brown grey and even white. The American mink is very similar to the native European mink. The main difference is the absence of a white upper and lower lip, and usually of a white chin, in the alien species. The American mink is also characterised by semi-aquatic habits and is adaptable to a variety of habitats. In general, it occurs associated with marine and freshwater habitats, for example along the coast and on the banks of rivers and lakes with dense vegetation. The key requirements are mostly specified by food (and dens) availability. The species has recently widened its range to urban areas, for example in Denmark it has often been seen in the canals in the centre of Copenhagen and in a number of harbours.

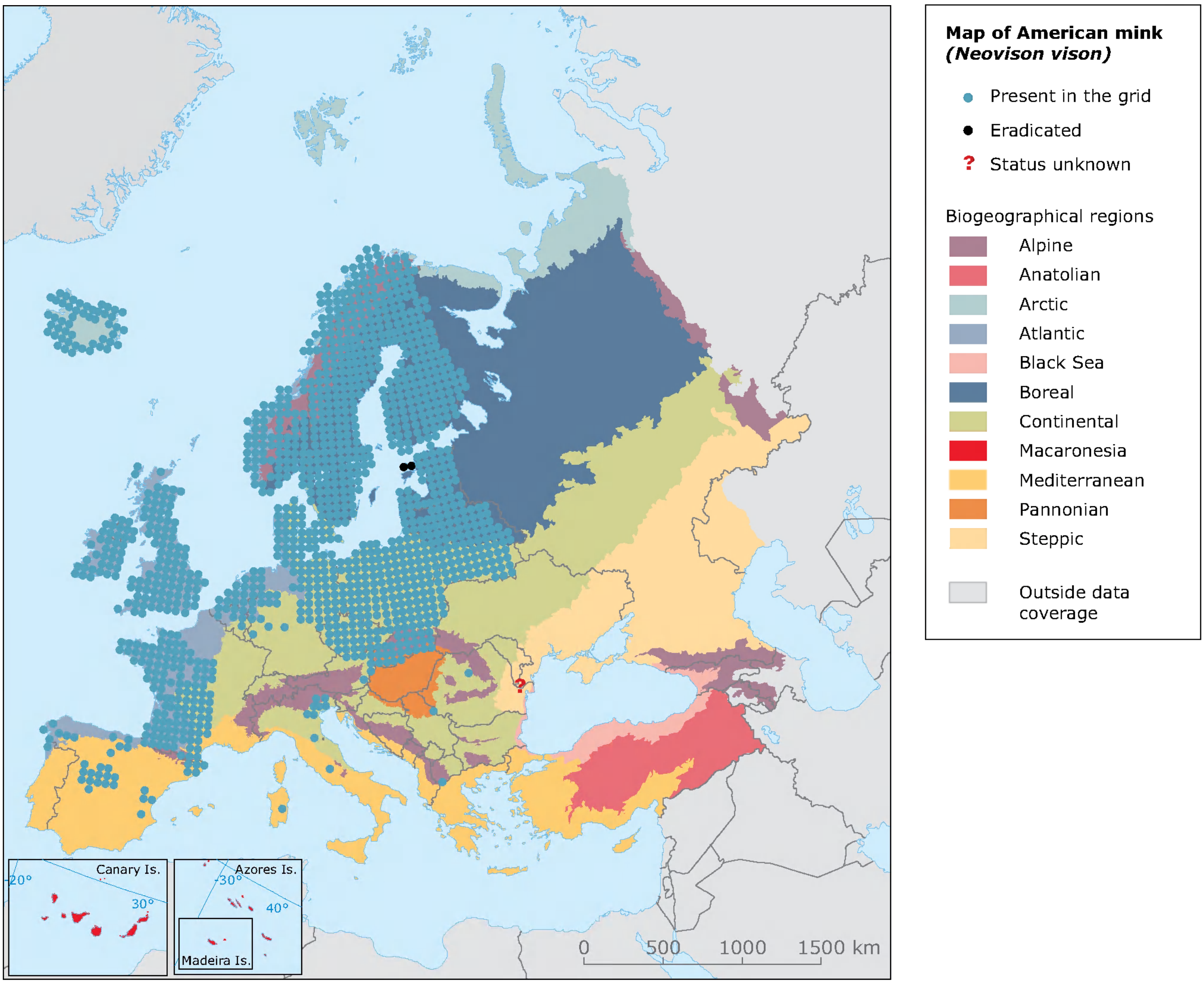
Impacts

The American mink is known to represent a major threat to many endangered indigenous animals, including the European mink and the European polecat. The way this generalist and opportunistic predator is affecting such species is through competition, and sometimes by direct aggression. In particular, the American mink is suspected of displacing the European mink. The current range of this close relative, threatened by extinction, is now restricted to only a few fragmented populations in Europe (but declines occurred also where there are no American minks). The impact of the American mink on native species can also occur through predation, and can be characterised by devastating effects. It is the case of some birds, especially colonial species and species occurring on islands in northern Europe and the United Kingdom, but also small mammals. For example, ground nesting birds (such as black-headed gulls and common terns) and small rodents (like the European water vole) have experienced significant population declines following predation from mink. The feeding habits of this predator, whose diet generally depends on prey availability (also linked to both the seasons and the habitat) may also affect amphibians, fish and crustaceans. The overall impact of mink predation can be further complicated by the presence of other prey, like the rabbit, which might always offer abundant food resources, preventing from the risk of food shortage. Interestingly, like in its native range, the American mink can prey extensively on muskrats also in Europe (e.g. in Germany and Poland), contributing to the control of the impact of this invasive alien rodent. The American mink can inflict damage also on some human activities, particularly on fish cultures (salmon farming) as well as on free ranging chickens, reared game birds, and — indirectly — on the eco-tourist industry, that is through predation on ground nesting birds. The economic impact of this species is however believed to be small on a national scale but can be locally important. Another impact of the American mink is related to its potential role as disease vector for other mustelids. A notable example is the Aleutian disease — a highly contagious virus affecting mink and other mustelids — that has been found in a feral population of mink and which could affect mink farming activities. Other diseases associated with the American mink are distemper, rabies and mink enteritis virus among others, but little is known about them.

Distribution and pathways

The native range of the American mink is Mexico, almost all of North America, except for the north of the Arctic Circle, and the most southern United States. The species was introduced for fur farming

Map of American mink (*Neovison vison*)



Source: Based on Genovesi and Scalera, 2008a.

in many parts of Europe starting from the 1920s, although intensive farming did not start until the 1950s. As a result of the many deliberate releases or escapes from farms, the American mink become common in the wild in most European countries. In fact, in addition to insufficient precautionary measures on farms, a major cause for dispersal and spread of the species has often been linked to the frequent 'liberations' by animal rights activists. Consequently the species is now widespread from Iceland, northern Norway and Russia, south to France, Italy and Spain. Other known introduced populations exist in the former Soviet Union, in South America (Chile and Argentina), and possibly also in Japan and other Asian countries.

In general, it seems that the abandonment of agriculture in wetlands led to an expansion of possible habitats suitable for the species. Today the species is considered to be increasing worldwide, although apparently decreasing in some European countries (e.g. Sweden and the United Kingdom).

Management

There are a number of experiences showing that it is possible to control or eradicate feral population of American mink from large areas. Some of them have been also financed by the EU through the LIFE programme, with the objective to increase opportunities for the conservation of the European mink. In archipelagos with many small islands, such removals can increase the breeding densities of many bird species. For example, a study on small islands in the Baltic Sea has shown that — as a direct effect of the eradication of American mink — the breeding success of some species (common ringed plover, Arctic skua, rock pipit) increased markedly, and some locally extinct species (razorbills, black guillemot) returned to breed in the area.

Also, in the Outer Hebrides in Great Britain an eradication attempt is near completion. At the moment, trapping followed by lethal control is the only feasible method for containing or eradicating mink. In general, live-traps are recommended to avoid affecting non-target species, and many initiatives are being carried out to test the effectiveness and best strategies for control trapping. Other evidence suggests that habitat management is a feasible option to mitigate the effect of American mink. An example is the restoration of reed beds and isolated ponds, which may provide refuges for water voles. A key preventative measure is to reduce the risks of further release and possible spread of the species from fur farms by developing a sound regulation of the license system and by a drastic improvement of the fencing system around the farms.

Impacts of IAS on biodiversity — competing with local species

American Bullfrog *Rana catesbeiana*

The American bullfrog

Species description

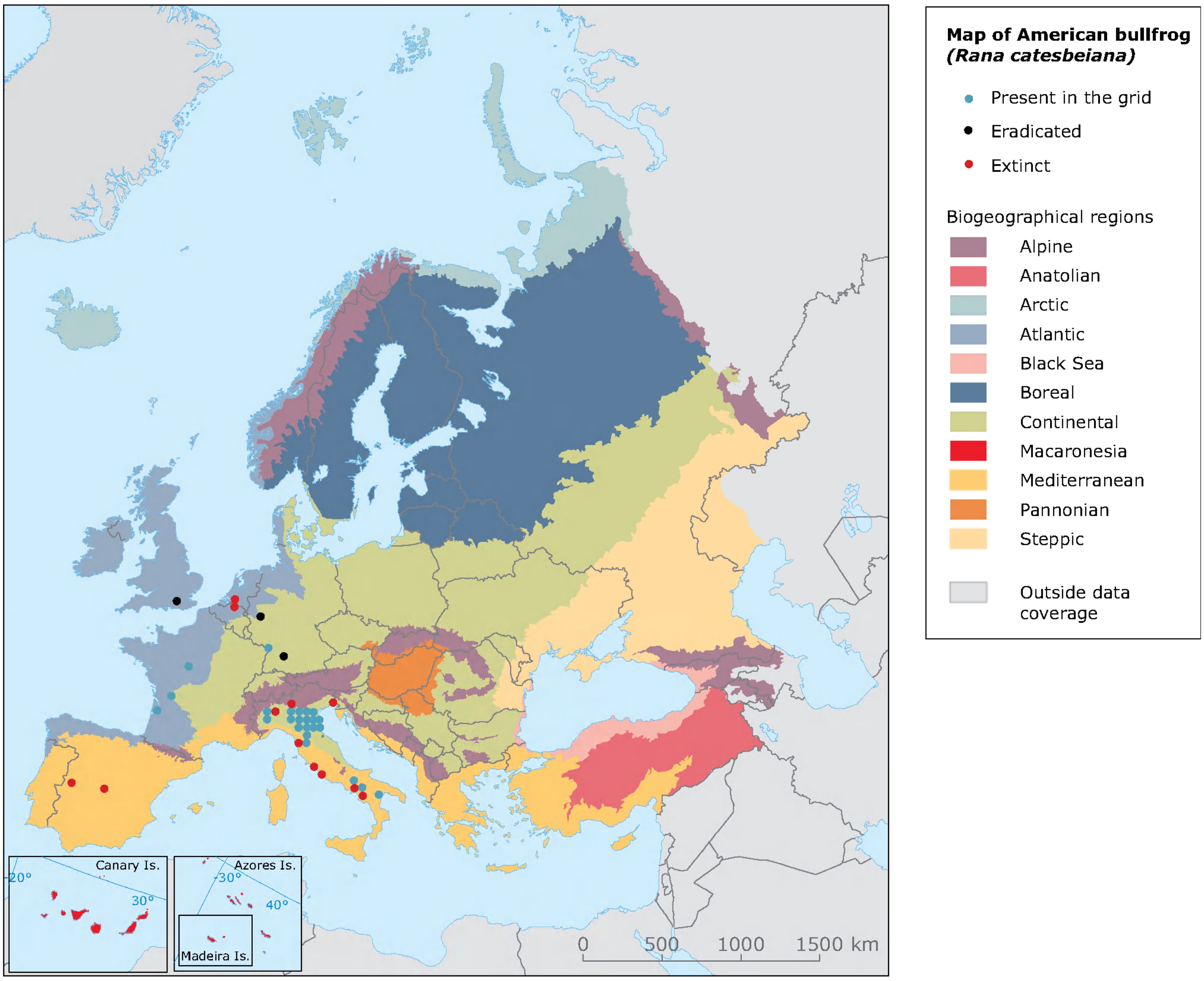
The bullfrog is the largest North American frog, whose adults can reach a snout-vent length of almost 20 cm and almost half a kilo of weight. Also, the tadpoles are gigantic compared to other frogs, as they can reach a length of 15 cm. Bullfrogs are characterised by a call that sounds sort of like the mooing of a cow or the roar of a bull, hence their name. They have a pale green to dark olive dorsal colour with possible brown spots, and a white, grey or yellowish ventral side. Moreover, they are characterised by conspicuous tympanic membranes — which are twice the diameter of the eye in mature males — and by the lack of dorsolateral ridges, typical of other European frogs. The American bullfrog lives in a wide range of aquatic habitats including lakes, ponds, swamps, bogs, marshes and backwaters. In fact, bullfrogs show some kind of preference for highly artificial and highly modified habitats, such as millponds, livestock grazing ponds, reservoirs, irrigation ponds and ditches. As a consequence, the establishment of bullfrogs may be favoured by human-driven habitat modification, such as changes in hydrology from seasonal to permanent water, removal of emergent vegetative cover and elevation of water temperatures (e.g. from increased sunlight).

Impacts

The bullfrog has the ability to colonise a whole range of habitats and to feed on many species. For this reason it is considered a serious ecological threat for many indigenous species in its introduced range. Like other naturalised species with a wide trophic niche, the bullfrog may compete for food with indigenous amphibians. A negative impact on native frogs has been notably stressed. For example, in North America the bullfrog is implicated in the decline of more than a dozen amphibian species. Competition may occur at both adult and larval stages. Studies have been carried out showing that bullfrog tadpoles may exert strong negative effect on indigenous tadpoles as a result of interspecific competition for the exploitation of resources (e.g. for algae). Indeed the diet of this voracious opportunistic predator — which includes a wide range of prey, from insects and other invertebrates to several vertebrates, such as amphibians and reptiles, small mammals and birds — seems to reflect habitat rather than food preference, a feature that increases its fitness in a wide range of ecological situations.

Another interesting case of interaction between bullfrogs and other indigenous species studied in North America regards the occurrence of interspecific amplexus with the red-legged frog and the Oregon spotted frog. This phenomenon could have negative demographic consequences for the indigenous frogs by reducing the numbers of males available to couple with conspecifics during the breeding period. On the other hand, the bullfrog seems to benefit from the presence of some other non-indigenous species occurring in the same ecosystem. For instance, in western North America a non-indigenous fish, the bluegill, is facilitating the bullfrog invasion by lowering the abundance of

Map of American bullfrog (*Rana catesbeiana*)



Source: Based on Ficetola et al., 2006.

indigenous dragonfly nymphs, which are one of the few predators of the unpalatable bullfrog tadpoles. Such positive interactions between non-indigenous species should receive greater attention, because they can be more common than currently known.

Bullfrogs represent a major conservation concern for native ecosystems also for the inherent risk of transmission of diseases and parasites to the native amphibian fauna. For example, the bullfrog seems involved in the spread of Chytridiomycosis, a fatal disease caused by the fungus *Batrachochytrium dendrobatidis* (Bd for short). The infection is typically asymptomatic in the bullfrog, which therefore seems to be an efficient potential vector of the fungus to native frogs. Current evidence suggests that their widespread transportation and release may have been a contributing source to the global explosion of the disease in the past two decades (although it is clear that in principle all traded amphibians can serve as vectors). Consistent with this hypothesis is that the first documented occurrence of Bd in Great Britain is at a site having the only breeding population of bullfrog in the country.

Distribution and pathways

The American bullfrog is native to the eastern part of North America, and has been introduced in the last century to the western part, as well as into more than 40 countries worldwide. In Europe the bullfrog is known to occur and reproduce in at least eight countries (Belgium, France, Germany, Greece, Italy, the Netherlands, Spain and the United Kingdom), although it seems to be established only in Belgium, France, Greece (Crete) and Italy. The bullfrog is an edible species that is now present in so many countries and islands of the world mainly as a consequence of escapes from breeding facilities (where the species was supposed to be farmed for human consumption and trade in aquaculture) but also from garden ponds. In some cases the species has also experienced intentional releases aimed at establishing wild populations to be regularly harvested (or to act as a predator of unwanted species, like insect pests in Hawaii). Recent studies have shown that only six independent introductions might have occurred in Europe, followed by secondary translocations of individuals from successfully established populations.

Management

The import of bullfrog has been suspended in the EU following the provision of the Wildlife Trade Regulations, but as a result of the intensive trade that occurred before the implementation of such legislation, a number of populations had already been introduced in the wild in the EU, and now need to be actively removed. The main strategies include isolation of breeding ponds with frog-proof fencing combined with pitfall trapping, netting, draining, electrofishing and shooting. Within the EU, eradication or control programmes have been carried out in, for example, France, Germany, the Netherlands and the United Kingdom. The foreseen cost to implement eradication/control measures for some localised populations was estimated at EUR 270 000 in Germany (for only 5 ponds, but the total cost would rise to EUR 4.4 billion in the event that this species spreads throughout the country) and GBP 100 000 in the United Kingdom (across seven ponds).

Impacts of IAS on biodiversity — predating local species

Brook trout *Salvelinus fontinalis*

The brook trout

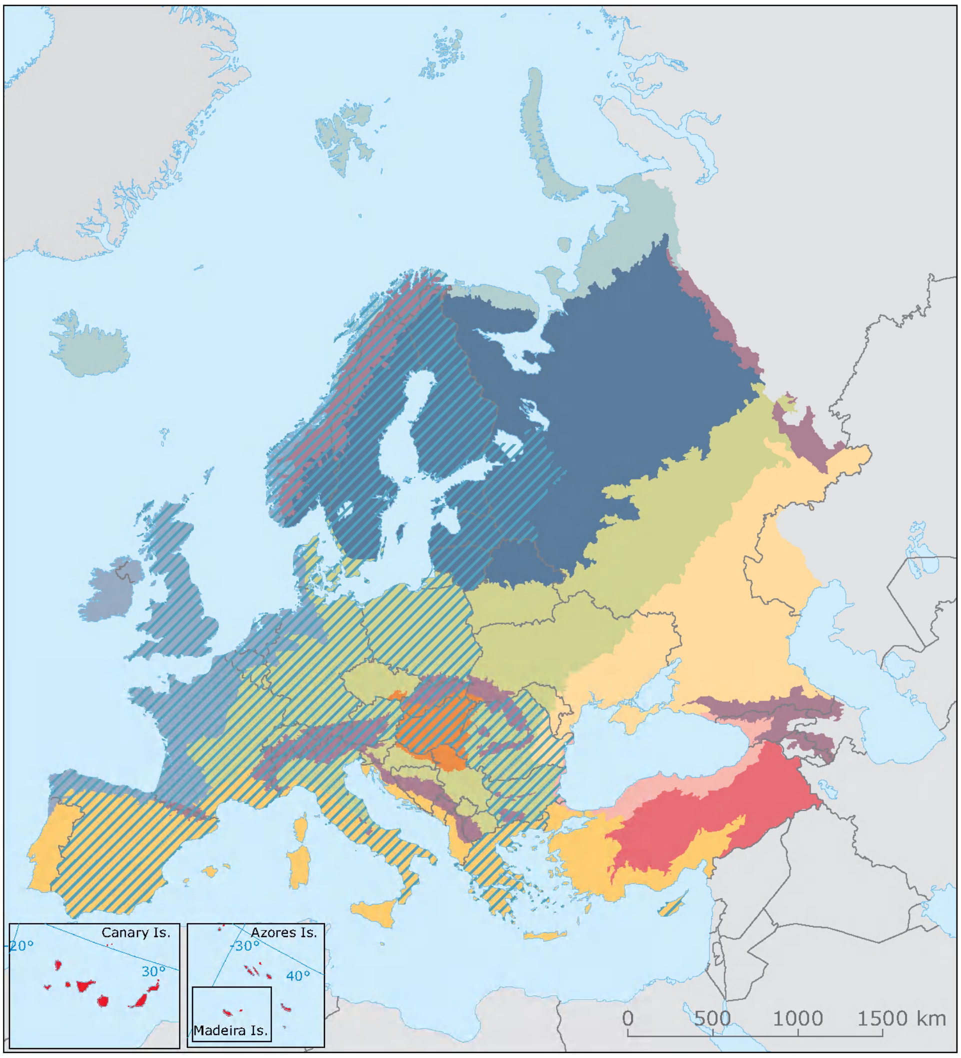
Species description

The brook trout, or brook charr, is a salmonid predatory fish with a long streamlined body, a large mouth that extends past the eye and an adipose fin close to the tail. The tail fin is slightly concave and the scales are very small. In its native range it can reach a length and weight of 86 cm and 9.3 kg, respectively, whilst in Europe it rarely exceeds a length of 45 cm and a weight of 1 kg. Colouring and appearance may vary with habitat and reproductive state. In general, the back has a distinct light marbled pattern of colour on olive, blue-grey to dark brown background, very similar to the native brown trout, but during the breeding season, males can develop a red colour along the belly, and both sides and fins turn red. The brook trout lives in a variety of habitats, including freshwater, brackish water and marine environments, for example in small streams, creeks, rivers and lakes, and prefers cool, clear, well oxygenated waters. Some populations of brook trout are anadromous, that is they spend part of their life-cycle in marine or brackish waters, but return to freshwater to reproduce. The brook trout may also grow faster and obtain a better condition and quality than the native brown trout in acid lakes, a trait that has made it attractive for stocking in waters where native species do not thrive or have disappeared.

Impacts

The introduction of brook trout for sport fisheries and aquaculture has often resulted in a severe impact on the native ecosystems throughout the world. This is mainly a consequence of the food habits of this predatory fish, which vary with age. In fact, although as fry (the first stage after the larval stage) it feeds primarily on insect larvae, as an adult it has a wide dietary range. In particular, adults are able to feed on diverse native organisms including worms, leeches, crustaceans, insects, molluscs, fish, amphibians and even small mammals, such as voles. In North America it is also considered an important predator of salmon eggs and juveniles. Introductions and stockings of brook trout have strongly affected not only the distribution and structure of native fish communities, but also distribution and abundance of amphibian and invertebrate populations. The description of general patterns of the impacts of this predator on stream prey is characterised by inherent difficulties, mostly due to the presence of multiple predators in the ecosystem, whose interactions can be complex and unpredictable. However, it seems that brook trout negatively affects and even replaces native salmonids. This is especially the case with brown trout, particularly in high altitude lakes and streams. Furthermore, this replacement seems to negatively affect the freshwater pearl mussel, through a very subtle mechanism. Brook trout cannot replace the brown trout and its role as host of the glochidiae, that is the larval stage of the mussel that needs to attach to the gills of a host fish, where it feeds as a parasite in order to survive during the winter. Thus, if native hosts decline, reproduction of the freshwater pearl mussel decreases and the future of the mussel — that is already considered as vulnerable by the IUCN Red List — is clearly at risk. In addition, the brook trout can hybridise with native brown trout, and some hybrids are known to be fertile, which can lead native populations to a loss of local adaptations and failure to reproduce.

Map of brook trout (*Salvelinus fontinalis*)



Map of brook trout (*Salvelinus fontinalis*)

Present in the country

Biogeographical regions

- Alpine
- Anatolian
- Arctic
- Atlantic
- Black Sea
- Boreal
- Continental
- Macaronesia
- Mediterranean
- Pannonian
- Steppic

Outside data coverage

Note: Only the countries of occurrence are indicated, because no further distribution details were available at the regional level.

Source: Based on Josefsson, 2008.

Furthermore, when brook trout is stocked in previously fishless oligotrophic mountain lakes, this alien species may alter the nutrient cycle and stimulate primary production by accessing benthic sources of phosphorus that normally would not be available to pelagic communities in such waters.

In conclusion, brook trout has detrimental effects to biodiversity and therefore is of serious concern and should be considered an important invasive species. However, this consideration needs to account for the recreational fishing community who see this species as providing social and economic benefits to local communities

Distribution and pathways

Brook trout is native to the eastern parts of North America, but today is widely distributed over most of Canada and the United States. This is a consequence of the frequent introductions carried out for sport fisheries, as well as for food production. Because of its popularity for aquaculture and sport fisheries, brook trout has also been introduced in other temperate areas of the world. It is currently present in more than 40 countries, including Africa, Asia, Europe, Oceania and South America. In Europe it was first introduced to the United Kingdom in 1869, and now is present in some 20 countries, from Spain in the south to Norway in the north.

Established brook trout can reproduce and spread naturally, and although stocking activities are decreasing in Europe, the species is increasing its range through reproduction and secondary spread. In fact, brook trout can disperse upstream from the point of introduction, also across barriers such as waterfalls or through mires at high water flow, thus potentially gaining access to the headwaters of adjacent drainage areas.

Management

Established populations of brook trout are difficult and costly to control; therefore, the key strategy should focus on prevention. It would be important to guarantee that further introductions or stocking with this species are avoided. Nevertheless, it is clear that non-authorised introductions may always take place. In this case, eradication or control measures should be envisaged. Experience shows that attempts to eradicate trout have varying degrees of success. Electrofishing and gill netting can be effective in small, contained environments such as mountain lakes and streams. Control through the use of selective piscicides such as rotenone can be effective and may be considered if deemed necessary, but it is important to take into account that it can pose serious risks to other species in the ecosystem; therefore, robust risk assessments followed by stringent protocols would be required before its application. According to several evidences, the removal of brook trout has indeed led to the reestablishment of various species including salamanders, frogs and zooplankton, for example through either restoration actions or natural recolonisation.

Impacts of IAS on biodiversity — predating local species

Common slider *Trachemys scripta*

The common slider

Species description

The common slider is a medium to large freshwater turtle with a carapace 20–60 cm long, characterised by prominent yellow to red patches on each side of the head (typically red on the red-eared slider *Trachemys scripta elegans*, the subspecies most frequently traded and consequently introduced in the wild). Common sliders occur in most freshwater habitats, including swamps, ditches, lakes, ponds and rivers, but prefer quiet waters with soft bottoms, abundance of aquatic vegetation and suitable basking sites. Key habitat requirements include clean waters with sufficient contents of oxygen, which are needed in winter time for hibernation. Although habits are known to be more riverine in the tropics, in Europe major rivers are also inhabited, for example the Tiber in Rome.

Impacts

The diet of this opportunistic predator changes progressively from highly carnivorous in juveniles to omnivorous in adults. As a result, common sliders feed on several species of plants and animals, from insects and other invertebrates to vertebrates, including amphibians and reptiles, small mammals and birds, in practice, every kind of animal they can capture. On the other hand, the antipredatory behaviour typical of some native amphibian tadpoles for protection from native terrapins is not shown in the presence of American common sliders. All this may reflect a very generalised impact on whole freshwater communities. In addition, adults predominantly eat various species of aquatic plants, and in specific circumstances can therefore heavily damage wetland vegetation.

Common sliders may have some impact on local biodiversity also through competition for food, basking sites and nesting sites with indigenous turtles. In Europe, there is a growing concern for the few remnant indigenous populations of European pond turtle, which are being silently replaced by the common slider. Moreover, the common slider is also known to endanger other species of turtles at the local level, such as the Caspian pond turtle in Cyprus.

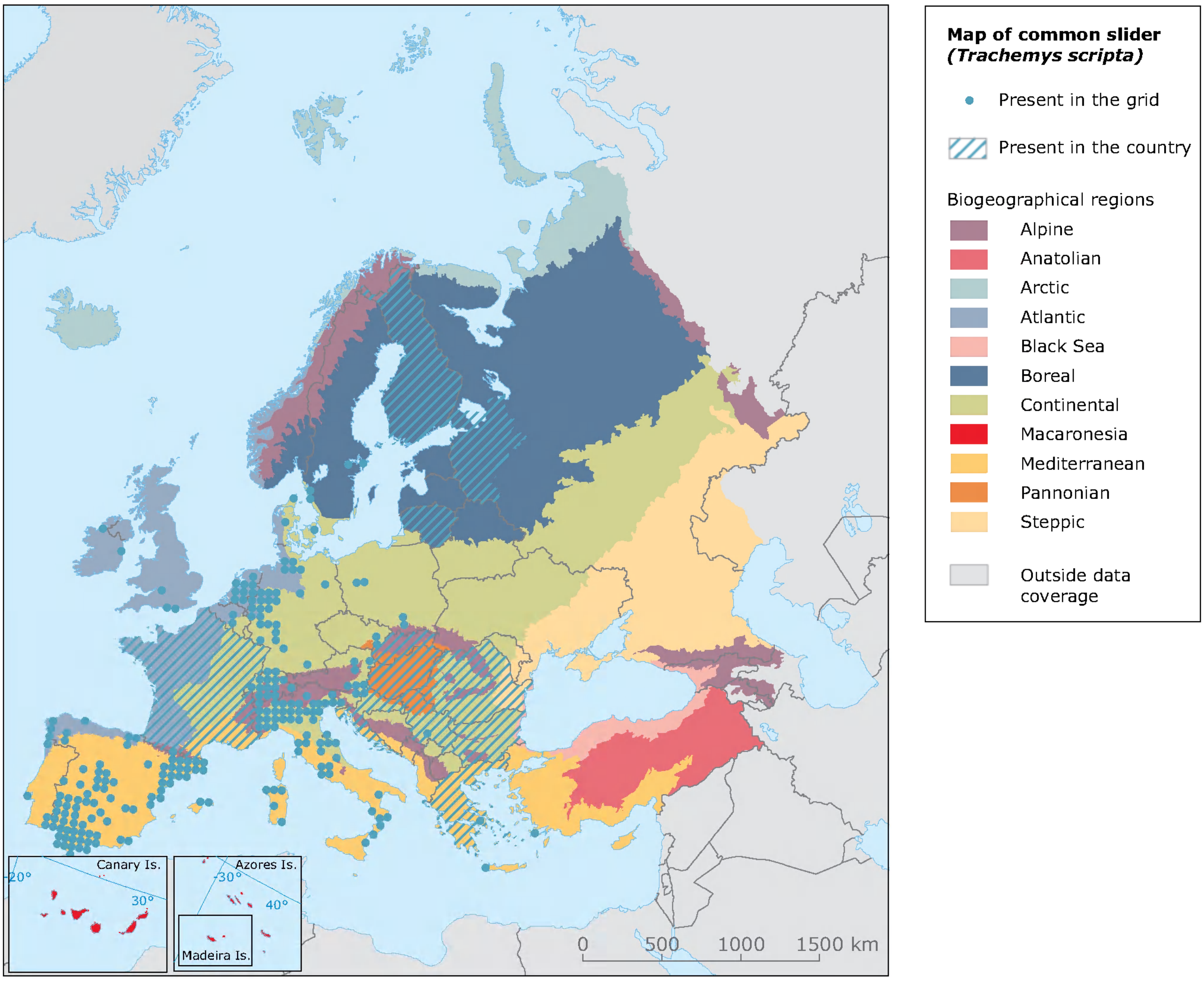
Common sliders can live for about 40 years, thus even if reproduction does not occur (which means that they cannot establish self-sustaining populations) the impact of single animals released in the wild can be enduring.

As many other species, the common slider is considered a potential vector for Salmonella, a gastrointestinal infection similar to typhoid, dangerous also to humans (often with serious complications including even meningitis, which explains the United States ban concerning the sale of hatchling turtles within the country since 1975). As documented by a rich medical literature accumulated in the last 30 years on this topic, many species commonly kept as pets could therefore place their owners, particularly children, at risk of dangerous illness following direct contact with infected animals. In the United States reptile and amphibian exposure is associated with about 6 % of the approximately 1.24 million sporadic human Salmonella infections that occur annually. It is worth mentioning that the ban did not affect the exports, and therefore United States bred turtles — particularly the red-eared slider — have continued to be spread throughout the world, as well with their questionable 'shipment' of parasites. However, in Europe such cases of disease transmission apparently have been very rare. Although the reasons for such differences remain unknown, it is possible that this is linked to the way that people keep turtles in their homes. In fact, sliders may also contribute to the spread of diseases and parasites (e.g. nematodes and bacteria) that could affect native turtles and other aquatic wildlife. In addition, large specimens can inflict painful bites.

Distribution and pathways

Though native to North America (eastern USA States and adjacent areas of north-eastern Mexico), the common slider is currently present in several countries throughout the world, for example south-east and Far East Asia, Bahrain, the Caribbean, Europe, Guam, Israel, Mariana Islands and South Africa. In Europe the species is present in at least 13 countries (Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden and the United Kingdom). However, breeding populations are known only in Germany and areas of the Mediterranean. The current distribution in most countries is poorly known due to lack of detailed information, but also to the very dynamic situation due to the continuous dumping in the wild of animals kept as pets. In fact, common sliders are among the world's most commonly traded pet reptile. In addition, they are marketed for human consumption, particularly in Asia. For example, between 1989 and 1997 the United States exported about 52 million red-eared

Map of common slider (*Trachemys scripta*)



Source: Based on Pobolšaj, 2008.

sliders. In countries like France, Italy, Poland and Spain trade in red-eared slider involved hundreds of thousands of individuals per year.

Management

Sliders can be captured by hand or through various trapping devices, like nets, fences and pitfalls. Floating boards used by sliders as basking sites seem very effective when equipped with baited cages on top. Sniffer dogs can be used to detect and remove both turtles and their eggs. Eggs can also be found and removed following females at nesting areas. As a major preventative measure, the import of red-eared slider has been suspended following the provision of the EU through the Wildlife Trade Regulations since 1997. However, the suspension of imports was not extended to subspecies other than red-eared sliders. As a consequence of this inconsistency, attempts to disguise the head diagnostic colours of specimen of red-eared slider have been made in order to smuggle them. Moreover, the trade switched to other North American freshwater turtles such as other subspecies of common slider, or many other species of freshwater turtles used as replacement species. Such replacement species — almost as harmful as the common sliders — have been already found in the wild, for example in Germany, Italy and Spain. One example is the painted turtle, whose import has also been recently suspended, after some populations started to reproduce in Germany. In the province of Rome, more than 10 species of alien turtles can be found altogether in some urban parks. In addition, although imports of red-eared sliders were virtually eliminated, trade in specimens bred in Europe has continued.

Other relevant management actions include the disposal of live specimens abandoned by amateur pet owners at rescue centres and zoological gardens, as reported for France, Italy and Spain. However, also in this case, accidental escapes seem to be contributing to opportunities for further spread of the species.

Impacts of IAS on biodiversity — transmitting or causing diseases or harm to local species

Red swamp crayfish ***Procambarus clarkii***

The red swamp crayfish

© Photo courtesy of Chris Lukhaup

Species description

The red swamp crayfish is a crustacean characterised by a dark red, orange, or reddish brown body, and a total length of up to 15 cm. The chelae, which are covered in spines and tubercles, are red on both surfaces. The red swamp crayfish is a large, prolific, aggressive species, with generalist and opportunistic feeding habits. It feeds mainly on succulent green plants, microbially-enriched detritus, invertebrates — both planktonic and benthic, including individuals of the same species — and amphibians. The red swamp crayfish prefers small but permanent waterbodies, although it is able to occupy a wide variety of wet habitats. Moreover, this species is well adapted to live in areas with drastic, seasonal fluctuations in water levels, for example during drought periods, where it survives by digging deep burrows (it can tolerate dry periods of up to months). Furthermore, it can tolerate low oxygen concentrations, and a wide range of water salinity and acidity. Such resistance to extreme environmental conditions, together with a resistance to crayfish plague, and other life history traits — for example short life-cycle, rapid growth, high fecundity, large numbers of offspring, early maturity at small body size — make this species particularly suitable for commercial exploitation but also a successful invader.

Impacts

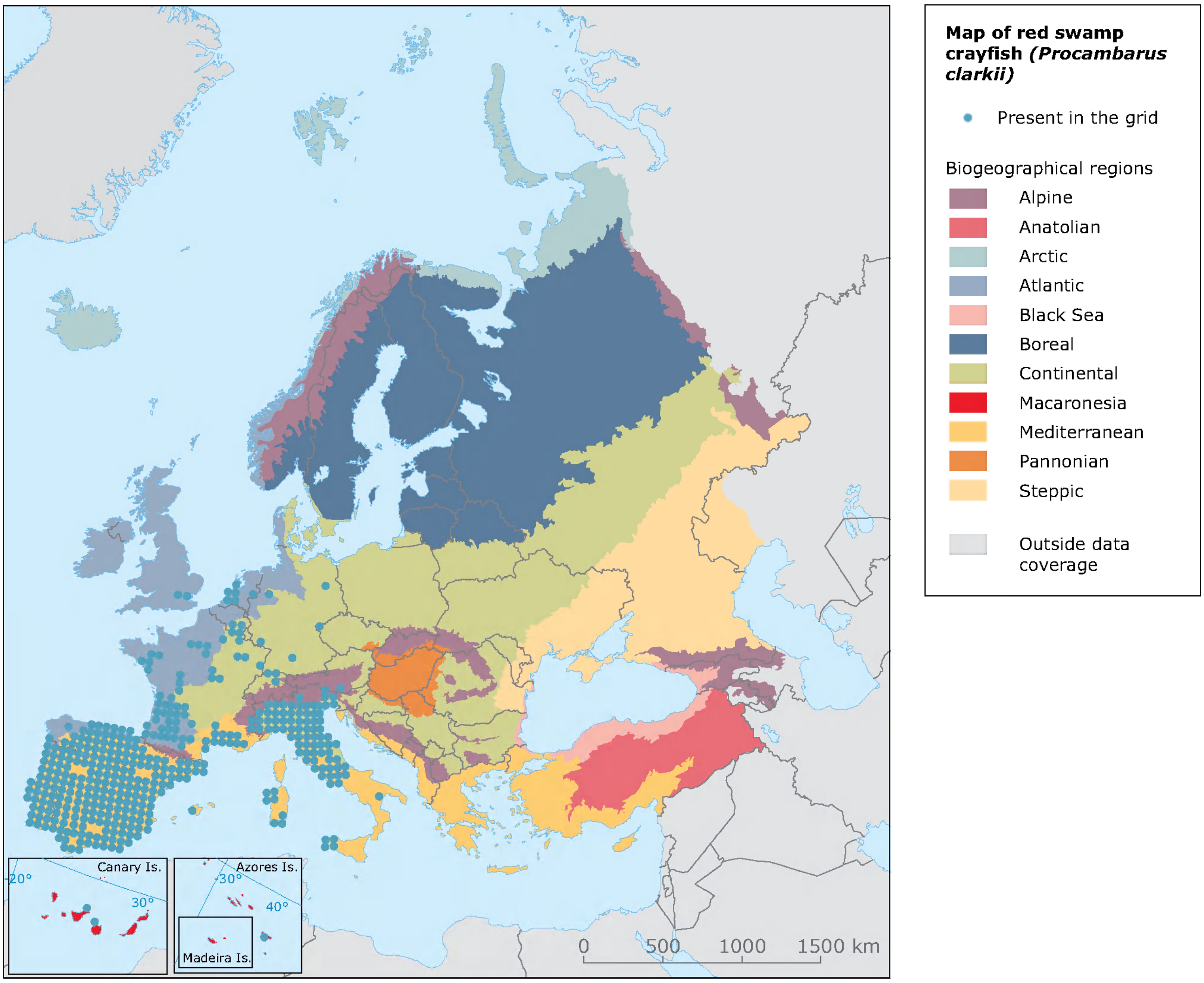
The red swamp crayfish is a proven chronic carrier of *Aphanomyces astaci*, a fungus-like organism responsible for the so-called crayfish plague in Europe. The introduction of this species (and other North American crayfish species) led to the accidental introduction of the crayfish plague in the 19th century. Interestingly, the impact of this pathogen could not be predicted from its innocuous effect on its native geographical range, that is toward

North American species. In fact, in North America crayfish act only as carrier vectors and *Aphanomyces astaci* rarely kills its hosts (the red swamp crayfish has been shown to be resistant to the disease).

Due to the missing co-evolutionary adaptation, this acute disease has created problems only in Europe. Native populations of European crayfish species are killed by the very aggressive pathogen in all infected watersheds. For example, it has contributed to the decline of the native European white-clawed crayfish, which is highly susceptible to the effects of crayfish plague. In addition, from the 1960s onward, the spread of this disease has led to the introduction in Europe of other replacement species of North American origin for farming and repopulation. As a result, new strains of *Aphanomyces astaci* were introduced. Unfortunately, over the 150 years that the disease has been present in European rivers, no resistant European crayfish have appeared. The red swamp crayfish is also associated with a virus causing vibriosis on crayfish farms and is an intermediate host for numerous helminth parasites of vertebrates. Some common trematodes could even be a potential pathogen of man and pets if crayfish are consumed without being properly cooked.

The red swamp crayfish is also contributing to the decline of the native European crayfish by replacing it. In general, this seems to happen in combination with other mechanisms, for example through competitive exclusion, differential susceptibility to predation and reproductive interference. Moreover,

Map of red swamp crayfish (*Procambarus clarkii*)



Source: Based on Gherardi 2008.

the red swamp crayfish may have significant impact on the food web structure of the invaded freshwater habitats by consuming invertebrates and macrophytes. Furthermore, because of its burrowing activity, it may cause significant economic damages in agricultural and recreational areas, for example rice plantations, irrigation structures, dams and dykes, as well as in rivers and lakes where they may destabilise banks, alter soil hydrology, increase water turbidity and cause water leakage.

In some cases, some positive effects of the red swamp crayfish have been recorded on the community of predators. For example, in Italy and Spain an increase in the number of little egrets, purple herons, cormorants and even endangered species, like the bittern, has been considered possible by the high densities of this crayfish species.

The red swamp crayfish may also represent a valuable resource for rural people, though this can be different from country to country. In Spain, for example, where the annual capture fishery has fluctuated in the last years between 2 000 and 3 000 tonnes, this alien species has brought undoubted economic benefit. Several hundred fishermen make their living year-round from this fishery, for example through their harvest and export, mainly to Scandinavian countries. On the contrary, in Italy the value of crayfish culture or fishery was very low due to low demand from the local fish market.

Distribution and pathways

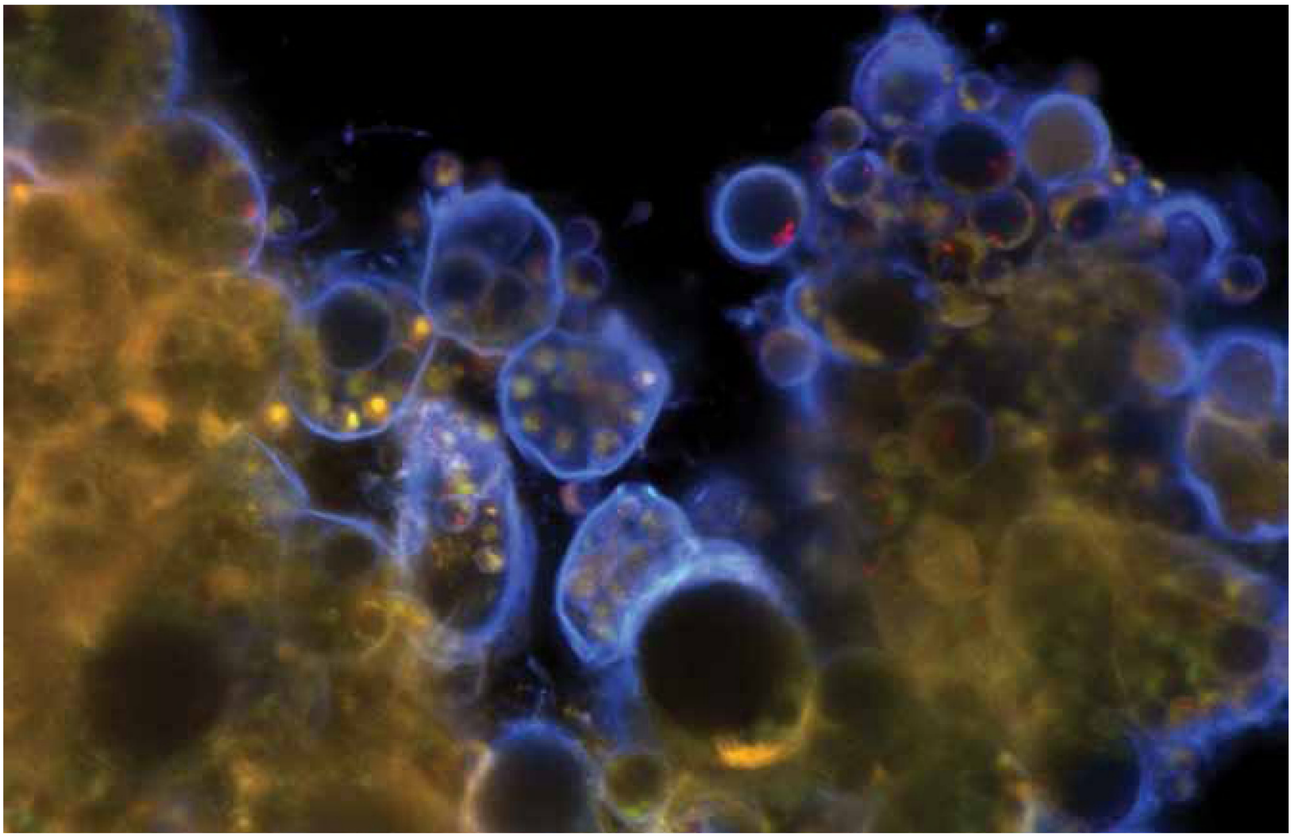
The red swamp crayfish originates from north-eastern Mexico and south-central USA. It has been introduced into several states on all continents except Antarctica and Australia, including parts of eastern and southern Africa, Eastern Asia, parts of Central and South America, several states of the United States outside its native range, and southern, central and western Europe. In Europe — where it is the dominant macroinvertebrate in several countries — it is increasing in many areas. It was first imported into Spain (in 1972) and later to Cyprus, France, Germany, Italy, Mallorca, the Netherlands, Portugal, Switzerland and the United Kingdom. Long-distance dispersal is facilitated by intentional introductions carried out mainly for aquaculture. In addition, the species has been traded as an aquarium pet and has been spread to new areas by anglers for local consumption and because it is used as bait. It can migrate long distances on land, even exceeding 3 km per day.

Management

The best way to mitigate the multiple impact of the red swamp crayfish (and its load of parasites and diseases) is to prevent its introduction by banning the import and translocation of live animals. Such initiatives should be supported by dedicated awareness-raising campaigns. The eradication of new populations is possible if promptly identified. Traps, fyke and seine nets, as well as electrofishing have been used as control methods, together with drainage of ponds, diversion of rivers and construction of barriers, either physical or electrical. As a complement to the traditional control methods, biocides such as organophosphate, organochlorine and pyrethroid insecticides could be used. Biological control methods, like the use of fish predators (e.g. European eels), of disease-causing organisms and of microbes that produce toxins, could also be effective. The use of sterile male release technique and of sexual pheromones to attract males is still under investigation.

Impacts of IAS on biodiversity — transmitting or causing diseases or harm to local species

Chytrid fungus *Batrachochytrium dendrobatidis*



Confocal micrograph of *Batrachochytrium dendrobatidis* in culture. Blue and bright yellow sporangia with red intervacuolar bodies are metabolically active cells, while opaque yellow sporangia indicate dead cells

Species description

Batrachochytrium dendrobatidis or Bd is a pathogenic microscopic fungus responsible for an infectious disease called chytridiomycosis. This disease is currently acknowledged as a leading cause of decline and extinction of many amphibian populations around the world. Bd infects the skin of amphibians and is the first chytrid species, out of approximately 1 000, that has been found to be a parasite of a vertebrate. It has not been observed to infect any other vertebrates (such as reptiles, birds or mammals) and thus does not represent a threat to human health. Despite the current progress and advances regarding the knowledge and understanding of the epidemiology of this emerging disease, there are many critical aspects of the natural history of Bd that remain unknown. These include mechanisms of spread, persistence in the environment, interactions with climate change, reservoir hosts and disease dynamics.

Impacts

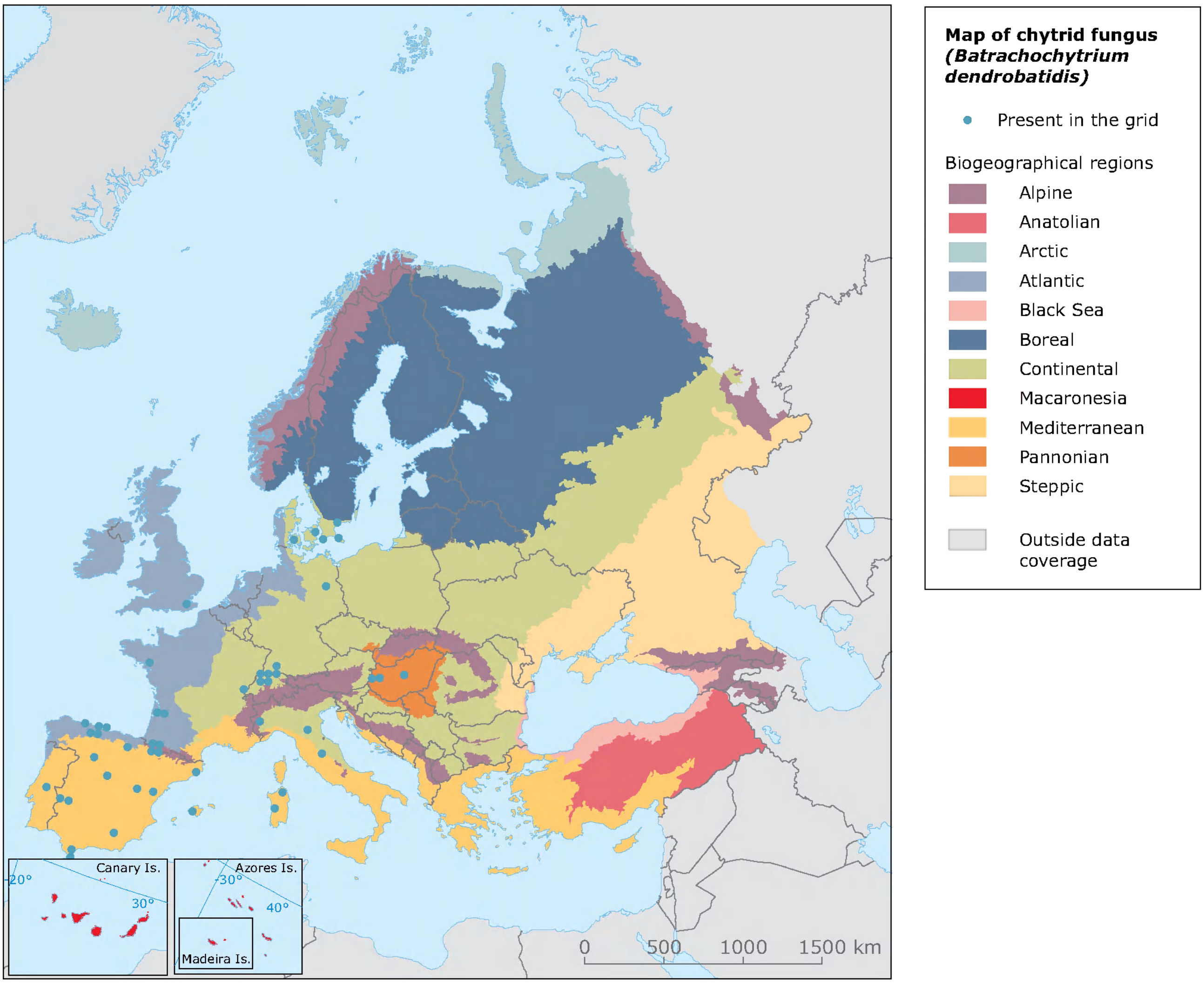
There is growing consensus among scientists that the spread of Bd has driven and will continue to drive amphibian species to extinction at a rate unprecedented in any taxonomic group in human history. It is estimated that about 92 % of amphibians considered 'critically endangered' by the IUCN Red List are undergoing declines that might be linked to Bd. Chytridiomycosis is currently known to infect at least 500 amphibian species (both anurans and salamanders) in about 40 countries spanning six continents, but these numbers are expected to rise as search efforts and reporting continue. Bd is also known to be widespread in Europe. Here, although the current knowledge on its distribution and impact on indigenous amphibians is still limited, we know that over one third of amphibian species have the pathogen present, and at least 10 % of the native ones are involved in chytridiomycosis-driven decline. For example, Bd-associated mortality has been documented in Spain in common toads, midwife toads and salamanders, in Italy in yellow-bellied toads and Sardinian brook newts, in Switzerland and Germany in midwife toads, and in the United Kingdom in natterjack toads. Furthermore chytridiomycosis mass mortalities are being monitored in Mallorcan midwife toad, Iberian ribbed newt, Tyrrhenian painted frog and palmate newt.

The mechanism by which Bd causes death in its host is linked to the damage that chytridiomycosis provokes on the skin of amphibians. Chytridiomycosis affects the ability of infected amphibians to respire or osmoregulate through their skin, resulting eventually in cardiac arrest. In addition to 'heart attacks', skin thickening can also cause suffocation.

Distribution and pathways

The presence of Bd is currently documented on every continent inhabited by amphibians, with the notable exception of Borneo, Madagascar and

Map of chytrid fungus (*Batrachochytrium dendrobatidis*) *



Note: * Only the main records are reported.
For example, if all records available for the Iberian Peninsula were mapped, the map would appear to be completely covered.

Source: Based on http://www.bd-maps.net/.

New Guinea (and of course Antarctica). Further, Bd appears to be widespread in both wild and captive amphibians in Africa, the Americas, Asia, Australia and Europe. The exact origin of Bd has not yet been determined. Recent attempts to identify the original geographic source population of Bd were equivocal (Africa, Japan and eastern North America have been proposed as ancestral centres of spread on the basis of genetic and historical evidence). Thus, two competing (although not mutually exclusive) hypotheses have been proposed. The first is the Novel Pathogen Hypothesis (NPH) according to which Bd was only recently introduced to new populations, where it is causing disease because of the lack of natural resistance to Bd infection. The alternative hypothesis is the Endemic Pathogen Hypothesis (EPH) according to which Bd has always infected amphibians all over the world and has just now begun to cause disease (maybe triggered by global change and other anthropogenic impacts on both host and parasite physiology).

According to the first hypothesis the original spread of Bd may be linked to the global trade in African clawed frogs. African clawed frogs were used from the 1930s onward to conduct human pregnancy tests. Once transported beyond their native range in Southern Africa, African clawed frogs were intentionally or accidentally released in the wild, with the result that today there are many naturalised populations, also in Europe (e.g. Italy, Portugal and the United Kingdom), where they are still traded as pets and for laboratory use. The peculiarity of these frogs is that they may represent an asymptomatical vector for the fungus, which they may carry on the skin without being susceptible to the disease. Another resistant species that for the same reason can be considered as a major carrier of Bd is the American bullfrog (in Europe infected animals have been detected in introduced populations in France, Italy and the United Kingdom).

Bd can apparently spread within an amphibian community by a combination of animal-to-animal and environment-to-animal transmission. In fact, Bd can survive prolonged periods (up to eight weeks) as a saprobe living in sterile pond water, without keratin, and this may partly explain its ability to persist at low host densities (e.g. when a population is almost extinct). In general, Bd requires water, or at least moist environments, for transmission and development.

There is increasing recognition that amphibian pathogens are being disseminated to new locations by anthropogenic means. This is mostly due to the fact that many people are unaware of the potential for animal pathogen transfer via their activities. This is not surprising if we consider that the transmission of Bd zoospores among either sites or amphibians can be facilitated by direct contact between an infected animal and an uninfected animal and by movement of equipment, such as people's boots and nets, between ponds or other water bodies.

Management

Detecting Bd is not an easy task. Due to the lack of specific clinical signs or symptoms, it is not possible to diagnose this disease with the naked eye. In fact, the diagnosis of chytridiomycosis is only possible with the support of specialised personnel and laboratory analyses, such as histopathology or advanced molecular techniques.

Chytridiomycosis is globally ubiquitous and cannot be successfully eradicated from affected sites. For the time being there are no effective methods to control Bd in the wild and there are no proven strategies for successfully managing affected amphibian populations. Recently, genetic factors that provide immunity to individual frogs have been identified. This is a very promising area of research to help the development of methods to control this disease in wild populations experiencing some population decline, because it focuses on the understanding of the factors that might explain why some amphibian species or populations are resistant to chytridiomycosis while others are not (in fact, it is known that while some amphibian species infected with Bd become sick and die, others do not). For example, among European species, the Sardinian brook salamander and the Mallorcan midwife toad are two species known to be susceptible to Bd, while the green frogs are apparently resistant to Bd. In several European countries there are also non-native species that are not as susceptible, like the American bullfrog, the cane toad and the African clawed frog that are present either as introduced populations in the wild or as traded animals or pets. From a conservation perspective, the presence of less susceptible reservoir hosts such as the species mentioned above is very important, because they may carry sub-clinical infections and act as vectors of the fungus.

The severity of the threat of Bd and its linkage with the global trade in amphibians is formally recognised by the World Organisation for Animal Health (OIE) with its recent decision to list chytridiomycosis as an international notifiable disease.

Impacts of IAS on biodiversity — hybridising with native species

Canada goose *Branta canadensis*

The Canada goose

Species description

The Canada goose is a large bird with a brownish-grey body plumage and a light breast, characterised by a black head and neck, with a white band under the chin. Also bill, feet and tail are black. The Canada goose prefers open, grassy habitats and lives in or near lakes and watercourses, marshlands, coastal plains, prairies and tundra, as well as in other types of terrestrial and freshwater habitats, for example in coniferous forests with access to water and forage. Moreover, like many other successful introduced species, the Canada goose manages well in habitats influenced by man. It is frequently also found in both agricultural and urban areas, such as city parks, golf courses and airports, close to humans. This omnivorous bird is primarily a grazer, and feeds on aquatic plants, grasses, roots, stems, leaves, seeds and fruit, including planted crops. On the other hand, juveniles feed mostly on insects, small crustaceans and molluscs attached to aquatic plants. The Canada goose can be confused with the native barnacle goose, but the latter is smaller, with a shorter neck, white face, black breast and a grey, rather than brownish, body plumage.

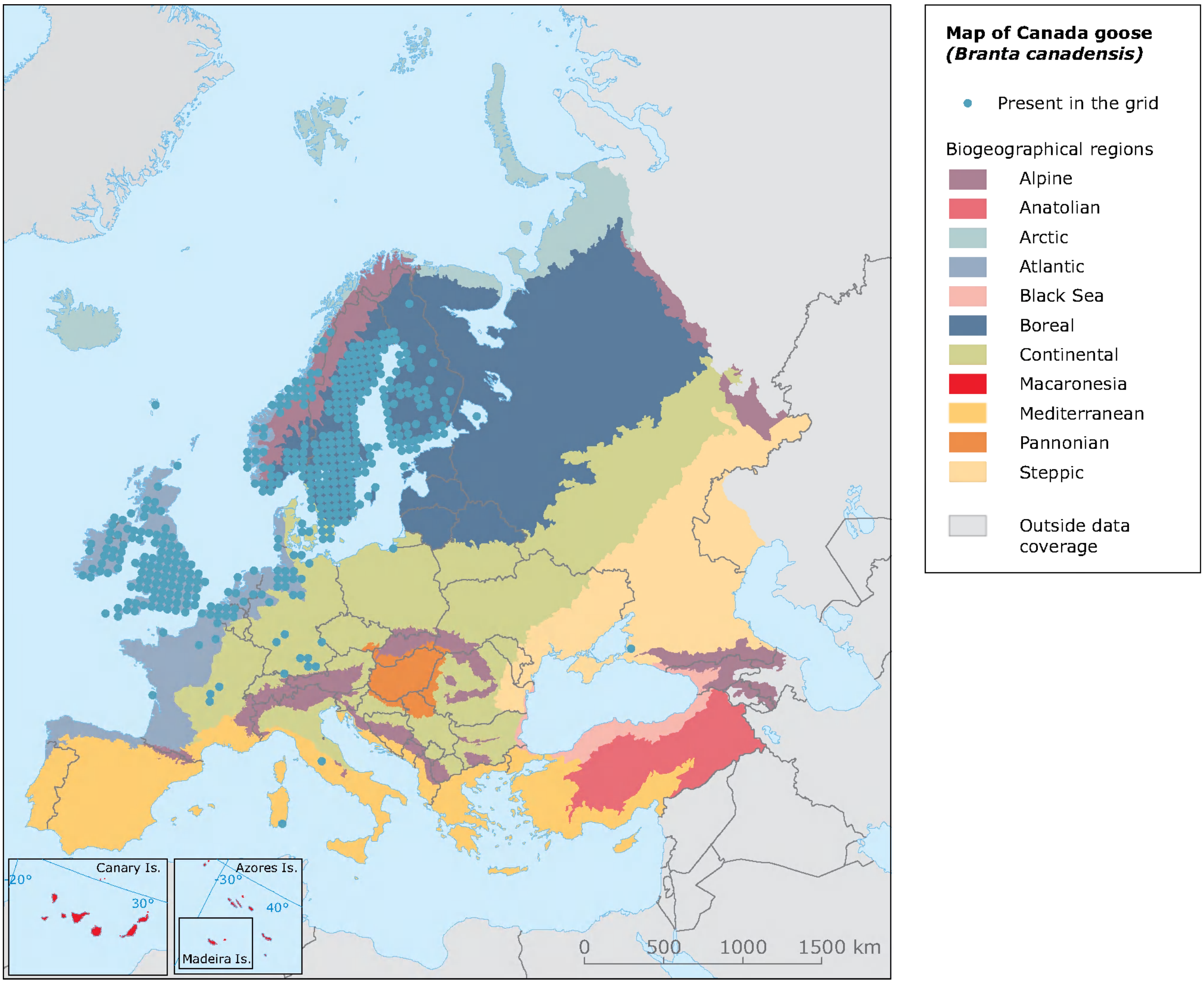
Impacts

The impact from Canada goose upon native species is controversial, but the hybridisation of the Canada goose with other species of geese, although thought to be rare in nature, is commonly observed in captivity. In particular, the Canada goose is known to hybridise with 16 species of geese, and even though hybrids observed in the wild may often be escapees, hybridisation is certainly known to occur in the wild. The mechanisms at the basis of this phenomenon are linked to some behavioural pattern typical of many other goose species. They include interspecific nest parasitism (i.e. when a nest and its eggs are taken over) and brood amalgamation (when hatched goslings are adopted). As a consequence of such adoptions, the offspring can be sexually imprinted on other species, with the result that once they will be looking for a mate, will search for a goose belonging to the same species as their foster 'parents', rather than a conspecific, and this will result in hybridisation. For this reason there is concern for the potential for hybridisation with other goose species, particularly for the already threatened lesser white-fronted goose, but also for the greylag goose, which seems the more common (it has been observed in the Faroe Islands, Germany, Iceland, Poland, and Sweden). Other crosses are known with snow goose, bar-headed goose, barnacle goose, bean goose and white-fronted goose. Hybridisation can occur also between the Canada goose and domestic geese.

Other types of impacts include competition with greylag goose and other aggressive behaviours (e.g. from territory displacement to killing of young and adults) against small waterfowl such as coots and moorhens.

Moreover, there are well documented cases of the negative effects of these geese on agricultural habitats, parks and recreational areas, resulting from feeding and trampling. Furthermore, the Canada goose may damage some habitats, like reedbeds, by grazing and trampling, and may cause algal blooms from eutrophication in water bodies due to the deposition of nutrients by defecating roosting geese. There is also some concern about human health hazard from soil and water contamination caused by excess droppings, which can serve as a vector for various diseases. Finally, given the attraction to the type of environments provided by airports for grazing and resting, the species seems to pose a certain threat to air safety from collisions with aircraft. For example, in 1995 a US Air Force AWACS aircraft crashed on take-off, killing all 24 people on board, after the engines ingested 13 Canada geese. In fact, in the United States alone, the economic costs, through loss of airtime or, in the event of a crash, entire aircraft, have been estimated at over USD 1 billion per year.

Map of Canada goose (*Branta canadensis*)



Source: Based on Shirley and Chiron, 2008a.

Distribution and pathways

The Canada goose is native to North America, including western Alaska, the Aleutian Islands, east across the Arctic mainland to Newfoundland and southern to northern parts of the United States. It has been introduced in several regions, including Australia, Europe, Japan, New Zealand and North and South Korea. In Europe it has been introduced in 11 countries in northern Europe, and across north-central Europe from Belgium east to Poland, and Russia. It was also introduced in other central and southern European countries such as Austria, the Czech Republic Italy and Switzerland where it is expected to become established as a breeding bird. This species has been introduced mainly as an ornamental species since the 17th century, but later on also for hunting. Today, escapees from aviaries, parks and zoos continue to add to the feral population, and additional secondary dispersal from the original points of introduction is contributing to a spread of the species in many neighbouring European countries (examples are Estonia, Iceland, Latvia, Lithuania and Poland). In total, the European population is considered to account for more than 350 000 birds, including up to 60 000 pairs.

Management

There are many different methods used to prevent the establishment of the Canada goose in the wild. One of the most effective methods is husbandry. This control method entails reducing the attractiveness of a site in terms of the food and/or space availability. Husbandry includes a variety of techniques which depend on the type of resources to protect (crops, recreational areas, airfields, etc.). There are also other effective non-lethal methods, such as physical deterrents (realisation of barriers or use of chemical repellents) or scaring devices or dispersal techniques (auditory, visual, physical). Specific habitat management techniques — removal of nesting sites, netting of ponds and lakes to prevent access to open water, and reduction of accessibility of forage through fencing or other obstacles — are also used, particularly to discourage nesting, roosting and feeding in airfields (e.g. in the United Kingdom). Lethal methods — like hunting — may be effective in agricultural areas, but not in urban ones. Populations are also reduced through treatment or removal of eggs.

Impacts of IAS on biodiversity — hybridising with native species

Ruddy duck ***Oxyura jamaicensis***

The ruddy duck

© Photo courtesy of Mark Hulme, WWT

Species description

The ruddy duck is a small diving duck with a characteristic long and sometimes erect tail, with males having a bright blue cobalt bill, black crown and nape, white cheeks and reddish body. This species inhabits almost exclusively freshwater habitats, preferably pools with fairly shallow bottoms and rich in aquatic plants. The ruddy duck feeds mostly on molluscs, insects and their larvae, but also on seeds and water plants. In the United Kingdom breeding grounds are represented by lowland waters of all sizes while wintering sites are typically large inland waters, such as reservoirs and large gravel pits where large numbers of ruddy ducks, in general 5–30 per flock, congregate.

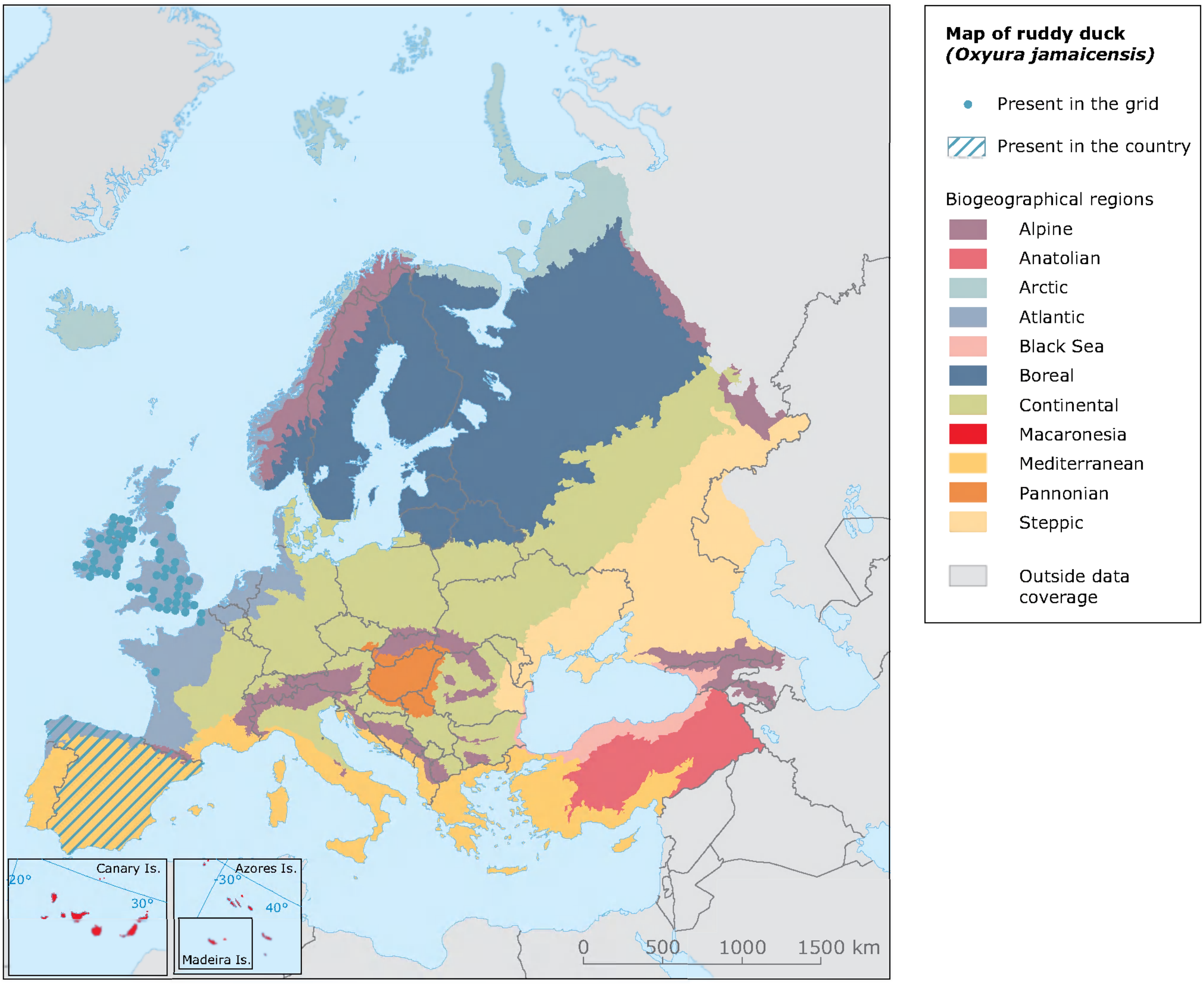
Impacts

Due to the concrete risk of hybridisation and consequent genetic swamping, the ruddy duck represents the greatest long-term threat to the white-headed duck's survival, particularly in Europe. The white-headed duck is a close relative of the ruddy duck currently considered as endangered on the IUCN Red List, because its highly fragmented populations have undergone a very rapid decline in the last decades. The white-headed duck — which was formerly found throughout much of Central Asia, southern Europe and parts of North Africa — is threatened by a number of factors, among which habitat loss (linked to unsustainable use of water resources and the recent drought in Central Asia), pollution, over-hunting and other forms of impact and disturbance from human activities (drowning in fishing-nets, hunting and ingestion of lead shot). These impacts are also likely to be exacerbated by the effects of global climate change. In Europe, where the breeding population of the white-headed duck is now restricted to Spain, the main threats to this species are represented by competition and hybridisation with the American ruddy duck. In fact, the two species, which belong to the same stifftail genus, have been geographically isolated for a few million years, and this prevented any possibility of gene flow. Now that the range of the two species partly overlaps as a result of the introductions carried out in Europe, the risk of genetic swamping constitutes a real threat for the indigenous species. The problem is that hybrids are fully fertile: while third-generation hybrids have been bred in captivity, second-generation birds have already been collected in the wild. Hybrids have been observed in Spain and Morocco since the early 1990s. In total, about 200 hybrids have been recorded, most of which were culled. The threat to the white-headed duck from the ruddy duck would be extremely serious if the latter would be allowed to spread across the Eurasian region, and particularly in the white-headed duck range states such as Algeria, the Russian Federation or Turkey. Finally, introduced ruddy ducks may also affect the populations of white-headed ducks through competition for food and nest sites.

Distribution and pathways

The ruddy duck is a native of the Americas, where it has a large, discontinuous range occurring along the Andean highlands from Colombia to Chile and in Canada, the Caribbean, Mexico and north-western and north-central USA. In the late 1940s four male and three female ruddy ducks were imported to the United Kingdom to be part of a private wildfowl collection. As a result of escapes

Map of ruddy duck (*Oxyura jamaicensis*)



Note: Due to the large reduction in the population in recent years the range is shrinking and it is likely that the species is not present in Scandinavia anymore.

Source: Based on Shirley and Chiron, 2008b.

of some offspring from these birds, the species soon became naturalised in the United Kingdom. Since then the United Kingdom population has increased rapidly, up to about 6 000 birds in 2000, and its range began to expand significantly also in other European countries, such as Belgium, France and the Netherlands (the only countries that hold significant numbers of birds) and, since 1983, in Spain. By the mid 1990s, ruddy ducks had been recorded in over 20 countries in Europe, from Belgium east to Turkey, south to Italy, Portugal, Spain and Morocco and north to Norway, and Iceland. Annual breeding attempts probably occurred in at least six countries in Europe, for example Belgium, France, Iceland, Ireland, Morocco, the Netherlands and the United Kingdom. DNA analysis confirmed that the European ruddy duck population is likely to be derived almost solely from the captive population in the United Kingdom.

Management

The ruddy duck has been the object of an ambitious eradication programme carried out in the United Kingdom from 2005 to 2011 and co-funded by the EU financial programme LIFE-Nature (total budget EUR 3.77 million). The programme, which resulted in a 95 % reduction in the ruddy duck population in 2010, was actually based on a number of preliminary control trials carried out in the United Kingdom since the early 1990s. These trials were aimed at assessing the feasibility of the eradication and at testing the best methodologies, during which (despite considerable controversy) many thousands of ducks were culled.

As a result of the eradication programme carried out in the United Kingdom and the control operations in other countries, (by 2004 at least 15 countries were taking actions to control ruddy duck populations, for example Belgium, Denmark, France, Hungary, Iceland, Ireland, Italy, Morocco, the Netherlands, Portugal, Slovenia, Spain, Sweden, Switzerland and the United Kingdom), the total population in Europe and the Mediterranean is now between 550 and 700 birds. On the other hand, the Spanish subpopulation of white-headed duck has now stabilised, and it is projected that the global decline will be reduced in the next years.

Ruddy ducks are now present in Europe in significant numbers only in four countries, namely Belgium, France, the Netherlands and the United Kingdom. Since numbers of ruddy ducks on mainland Europe now exceed those in the United Kingdom (whose population is now believed to be fewer than 100 birds, including Northern Ireland) eradication in France and the Netherlands (where there are about 50 and 20 breeding pairs, respectively) must follow if the success of the United Kingdom programme is not to be compromised. In the United Kingdom, full eradication is feasible and therefore additional work is being funded. The Standing Committee of the Bern Convention agreed that ruddy ducks should be eradicated across Europe by 2015.

Nevertheless, it is known that some very small populations (10 or fewer birds) occur in a large number of other countries. For example, only one ruddy duck was recorded in Spain in 2010 and eventually culled in 2011. Therefore, the United Kingdom is no longer the sole source population of ruddy ducks in Europe. Rapid increase and further expansion will be inevitable unless concerted control is undertaken in all core countries. Given the eastward expansion, one of the main areas of concern now is the presence of ruddy ducks in other countries in eastern Europe, and also in North Africa (particularly in Algeria, Morocco and Tunisia) which might run the risk of being undetected or unreported. It is clear that to do nothing would eventually allow ruddy ducks to spread through the Eurasian continent.

The import of ruddy duck is now suspended by the EU Wildlife Trade Regulations on the grounds that it poses an ecological threat to indigenous species. This now gives Member States the opportunity to place restrictions on or ban the keeping of ruddy ducks in captive collections, thus contributing to stop the spread of the species in Europe.

Impacts of IAS on biodiversity — affecting habitats — ecosystem engineering or modifying or changing habitats

Rabbit *Oryctolagus cuniculus*

The rabbit

© Photo courtesy of Keith Springer

Species description

The rabbit is a small mammal of the family of leporids, with a grey-brown fur and white-grey belly. Its diet includes a wide range of species of grasses, forbs and other herbaceous vegetation. Rabbits can be very selective in their choice of food (there may be local specialisation on a few preferred species), and can also practise coprophagy, and ferment food in the hind gut. Rabbits live in a number of habitats, such as agricultural areas, desert, natural and planted forests, grasslands, ruderal areas and shrublands, disturbed habitats and urban areas, but the preferred habitat types in their native range are oak savannah and grassland mattoral. Rabbits tend to avoid cold and wet conditions, and are absent from alpine lands, unbroken scrub and heavily built-up areas. The reproductive cycle is characterised by a high fecundity rate, females are capable of reproducing in their first year and average annual litter sizes are around 10–13 (in southern Europe). Population size is limited by climate (thermal limits, rainfall, and vegetation quality and quantity), terrain (available substrate for burrowing and soil type suitable for their major food), predation pressure (density and diversity of predators) and, more recently, introduced pathogens.

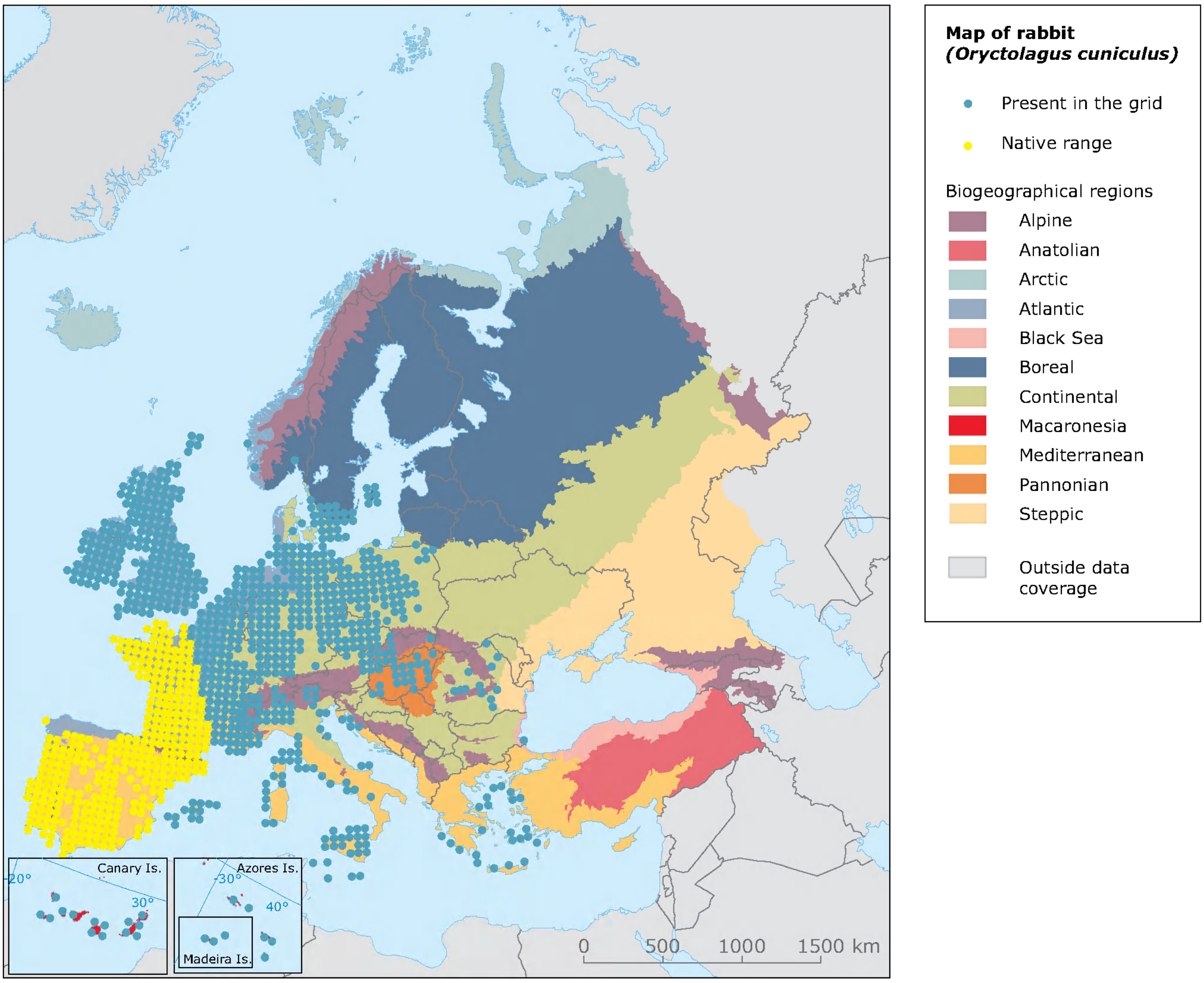
Impacts

The rabbit is an excellent example of the complex effects that an introduced mammalian may exert on the ecosystems to which it has been introduced. One of the most negative impacts showing the role of rabbits as key drivers of ecosystem change, includes habitat degradation following overgrazing, which in turn is responsible for altering the composition and local abundance of both animals and plants. In this way the stability of many ecosystems, particularly islands, are often threatened by the trophic-cascade effects initiated by rabbit introduction. The impact of a trophic-cascade effect can be very difficult to reverse, because once a new balance has been achieved the subsequent removal of rabbits may have detrimental effects on the remnant communities (as vividly demonstrated by the fact that many predator species declined after the outbreak of myxomatosis, a virus introduced to control the rabbit populations).

Rabbits can indeed cause severe damage to the natural environment, including agricultural areas. They cause extensive erosion of soils by overgrazing and burrowing which in turn can cause significant impact on native communities (e.g. loss of plant cover and destruction of habitat of small animals). Examples of this kind of perturbations are common on islands (particularly small oceanic ones) where an introduced population can quickly exhaust all available resources and impact on native species that depend on undamaged ecosystems. A typical situation is the alteration or even the destruction of valuable seabird habitats.

As demonstrated by a rich literature, introduced rabbits impact on native fauna, both directly and indirectly, via a range of differing mechanisms. Such mechanisms may interact synergistically and result in population crashes or extinctions of native species. For example, competition with native wildlife for food and shelter is another problem, as this can lead to a decline in the numbers of

Map of rabbit (*Oryctolagus cuniculus*)



Source: Based on Mitchell-Jones et al., 1999.

Rabbit — a conservation paradox

The European wild rabbit, a native to southern Europe (Iberian Peninsula) and possibly Northwest Africa, is considered a 'conservation paradox', for although it is a highly successful coloniser around the world, it is threatened within its native range. Across the Iberian Peninsula, in fact, a combination of introduced viral diseases (including Myxoma virus and rabbit calicivirus), overhunting, habitat loss, changes in land use and living under intense natural predation pressure have caused a serious decline in rabbit populations. Since in this region the rabbit is considered a keystone species — one that is crucial in maintaining the organisation and diversity of ecological communities — its decline may affect many ecosystem services both directly and indirectly. For example, it is known that in its native Iberian range the rabbit is an important prey item for over 40 vertebrate predators; therefore, the survival of some seriously threatened predators, such as the Iberian lynx and Spanish imperial eagle, is clearly dependent upon its populations.

many native plants and animals. Of course, rabbits compete for food also with livestock.

In addition, the negative impacts on native species can be enhanced by the fact that the availability of non-indigenous prey may support and thus inflates predator populations (whether introduced or native, e.g. cats and foxes), which consequently increases predation rates on indigenous species.

The presence of rabbit may apparently benefit species and ecosystems also in its introduced range. In Germany and the United Kingdom, for example, the rabbit performs significant ecosystem services for nationally rare plant species, by maintaining short sward heights in heathland and grassland ecosystems, and serving as a prey item for populations of predators. Also in Sicily, the rabbit is considered a main prey item for the endangered Bonelli's eagle. Finally, the European wild rabbit is also of economic importance as a game species and as a domestic animal.

Distribution and pathways

The rabbit, a native to southern Europe (Iberian Peninsula) and possibly Northwest Africa, has been introduced to all continents, except Antarctica and — although with mixed success — onto over 800 different islands or island groups, where in the past it was often released as a food source for marooned sailors. It was first transported around the Mediterranean by Roman and Phoenician traders. After being domesticated in France between AD 600 and 1000, domestic rabbits were introduced in Britain in the 12th century. Later on rabbits were introduced throughout the world, for example in Australia, Chile, New Zealand and South Africa, and also through the active support of dedicated acclimatisation societies.

Management

Since the rabbit is in many areas where it is an introduced species, considered a nuisance or pest species, the many methods that have been used for controlling it in its introduced range include: fencing, warren ripping, baiting, fumigating and biological control, for example with myxomatosis, rabbit haemorrhagic disease virus and fleas as vectors. Management practices presently used in Europe do not include biological control, as native populations can also be affected. Rabbits have been eradicated from a number of islands, some of notable size (e.g. Enderby Island, in New Zealand, 710 ha). Nevertheless, not surprisingly the eradication of rabbit from some sites carries the inherent risk of generating more problems, because of the impacts of trophic cascades stemming from the role of rabbit in the new ecosystem, for example dependence on rabbits by native predator assemblages or by habitat. In stark contrast, the species is now a subject of intensive conservation efforts in Spain and Portugal, for example as a key component of a number of LIFE projects aimed at ensuring the recovery of the Iberian lynx populations.

Impacts of IAS on biodiversity — affecting habitats — ecosystem engineering or modifying or changing habitats

Killer algae *Caulerpa taxifolia*

The killer algae

Species description

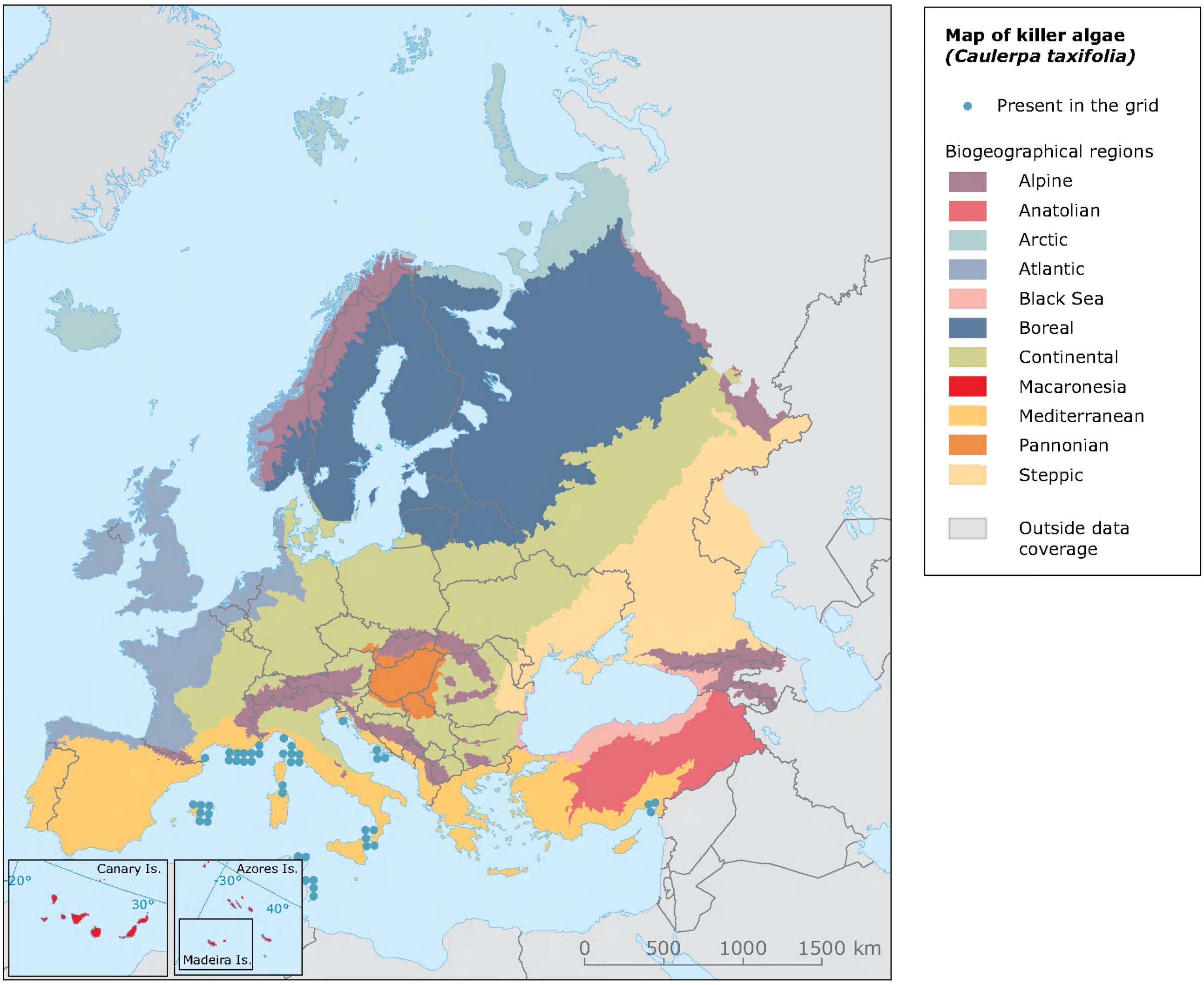
Caulerpa taxifolia is a seaweed used in tropical aquariums also known as 'killer algae' for the threat it represents for marine ecosystems. This green macroalgae has upright leaf-like fronds arising from creeping stolons, which are compressed laterally and can reach a length of up to 60 cm in deeper waters (but no more than 15 cm in shallow waters). The algae, characterised by a high growth rate and the ability to spread rapidly, can form dense meadows on various substrate (up to 14 000 blades per m^2), and is able to withstand severe nutrient limitation as well as eutrophic or polluted conditions. It can grow almost everywhere, from the surface to the lower limits of underwater vegetation (20–30 m in depth, although it has been collected down to 100 m in depth), from rocky capes swept by storms and currents to the soft bottoms of sheltered bays, from the polluted mud of harbours to habitats with a rich biodiversity. The exact mechanism of sexual reproduction is not clear, but it can certainly reproduce vegetatively via fragmentation. Another peculiar feature of this species is the production of a chemical defence mechanism which ensures the protection against epiphytes and herbivores, such as molluscs, sea urchins and fish, at least during summer and autumn. It produces a powerful repellent endotoxin, the caulerpenyne. Not surprisingly, this macroalgae has no natural enemies in the Mediterranean.

Impacts

The spread of the killer algae in the Mediterranean Sea has dramatically altered the native ecosystems, leading to the formation of homogenised microhabitats and to the replacement of native algal species. As a consequence of its spread, this killer algae has not only wiped out native algae, but has also displaced the native vegetation and has drastically reduced the marine biodiversity, for example by destroying fish nurseries and spawning habitats. The list of organisms affected by this algae is very long, and in addition to other algal species, includes sea-urchins, fishes, amphipods and polychaetes. Moreover, under certain conditions, it has out-competed the Neptune grass *Posidonia oceanica* (also known as Mediterranean tapeweed) which is a seagrass endemic to the Mediterranean. The Neptune grass is a flowering plant which forms large underwater meadows — better known as Posidonia beds — which are experiencing widespread decline due to a combination of direct anthropogenic pressures and climate change. The replacement of Mediterranean seagrass by the killer algae seems related to the stress level in the environment, due for example to the vicinity of sewage outfalls and storm water drains. Yet the killer algae is contributing to the loss of this important habitat which provides food and cover to a rich community of marine organisms and as such represents an essential living and breeding habitat for various species.

In the habitats invaded by the algae, the species community composition is strongly modified, and also other ecological parameters (such as number of species, number of individuals, the biomass and the mean weight) are negatively affected. For example, a study focusing on the striped red mullet has shown that the reduction of space between fronds due to the dense meadows formed by the killer algae may

Map of killer algae (*Caulerpa taxifolia*) sensu lato because two (maybe three) varieties of *taxifolia* occur in the Mediterranean Sea



Source: Based on Galil, 2008.

limit accessibility to resources and may increase intra-specific food competition. In addition, because killer algae beds have a different height, stiffness and density compared to seagrasses, these changes in habitat type modify the interaction of the seafloor with hydrodynamics, influencing key processes such as sediment resuspension and particle trapping. A major effect of such changes may be related to the fact that given the weak rhizome structure of the killer algae, the sediments may be unprotected during winter storms, when most erosion occurs. But it will also influence sediment biochemistry, nutrient cycling, water-column oxygen profiles, water filtration capacity, primary and secondary production, carbon storage, support of higher trophic levels and the ecosystems response to disturbance. Hence, the replacement of seagrass beds is likely to have a major influence on annual sediment dynamics at ecosystem scales.

By affecting the biological stability of the marine environment, the killer algae infestations have also negatively impacted several local activities along the Mediterranean coast such as recreational diving, tourism in general and the fishing industry. The impact on the Posidonia beds is therefore a clear example of how this algae is affecting key ecosystem function and services.

Distribution and pathways

The killer algae is a species originally distributed in warm tropical waters of North Australia, the Caribbean coasts, southern China Sea, East African coast, Fiji, Gulf of Guinea, Hawaii, northern Indian Ocean coastal areas, Japan, the Maldives, New Caledonia, the Red Sea and the Seychelles.

In 1984 a genetically altered type of this seaweed, very popular as a decorative in the marine aquarium trade, was accidentally introduced into the Mediterranean Sea possibly with aquaria outflow from a public aquarium in Monaco. Further to secondary spread facilitated by shipping and currents, particularly in harbours, marinas and other places where boats anchor (seaweed fragments can be transported also by fishing nets and ballast water), the killer algae is now dominating large patches along the Mediterranean coastline where it forms dense carpets, and is still progressing unchecked into new habitats. The aquarium-bred strain (mutated by years of exposure to chemicals and ultraviolet light which altered and switched on genes that were not previously present or active) is characterised by morphological and physiological characteristics which are unusual compared to the tropical populations. They include larger and longer fronds, a higher population density, adaptation to a larger spectrum of temperatures (as it can grow even in cool waters), increased sedimentation rates and higher concentrations of toxic metabolites. Recently, this seaweed has also colonised Southern Australia and the western coast of the United States (from where it has been promptly eradicated).

Management

The suggested methods of eradication to halt the spread of this invasive species include manual uprooting, underwater suction devices, physical control with dry ice, hot water jets and underwater welding devices to boil the plant, electrolysis with copper electrodes, and the use of chlorine and other chemicals (copper and aluminium salts). Some studies on biological control through potential predators like molluscs and nudibranchs are being conducted although there is some obvious concern for the potential risks associated with the introduction of further grazing tropical species in temperate waters.

With the only notable exception of the early eradication of the species in Californian waters (done through the use of a herbicide applied under plastic sheets covering the sea bottom infested by the seaweed), and a few localised initiatives (e.g. some manual eradication by divers, implemented at Mallorca in the Balearic Islands and Port-Cros in France), other attempts at eradication have failed and basically no control strategy has been established.

Impacts of IAS on ecosystem services — interfering with supporting services (6)

Japanese knotweed *Fallopia japonica*

The Japanese knotweed

Species description

Japanese knotweed is a herbaceous perennial plant with erect hollow stems that can grow up to 4 m in height. It can grow rapidly at up to 30 cm per day. Stems arise from a strong rhizome system that penetrates up to 3 m in the soil, can reach up to 20 m length and makes up two thirds of the plant's biomass. Leaves are 10 to 18 cm long, have a straight base and lack trichomes on the veins of the underside, which separates this species from two congeners, the Sachalin knotweed, which is native from eastern Russia (Sakhalin Island) to northern Japan and Korea, and their hybrid, the Bohemian knotweed, that probably originated in Europe in the 19th century, but was only scientifically recognised in 1983. Knotweeds are dioecious, which means that there are separate male and female plants. They are pollinated by unspecialised insects and seeds are dispersed by wind and water. Vegetative reproduction by rhizome fragments, however, prevails in the introduced range of this species. This leads to large stands that are genetically identical. Indeed, the Japanese knotweed present in the United Kingdom is considered to be a single female clone. It grows in riparian habitats, road and railway banks, alluvial forests, landfill and waste land, and at fallow land and ruderal sites.

Impacts

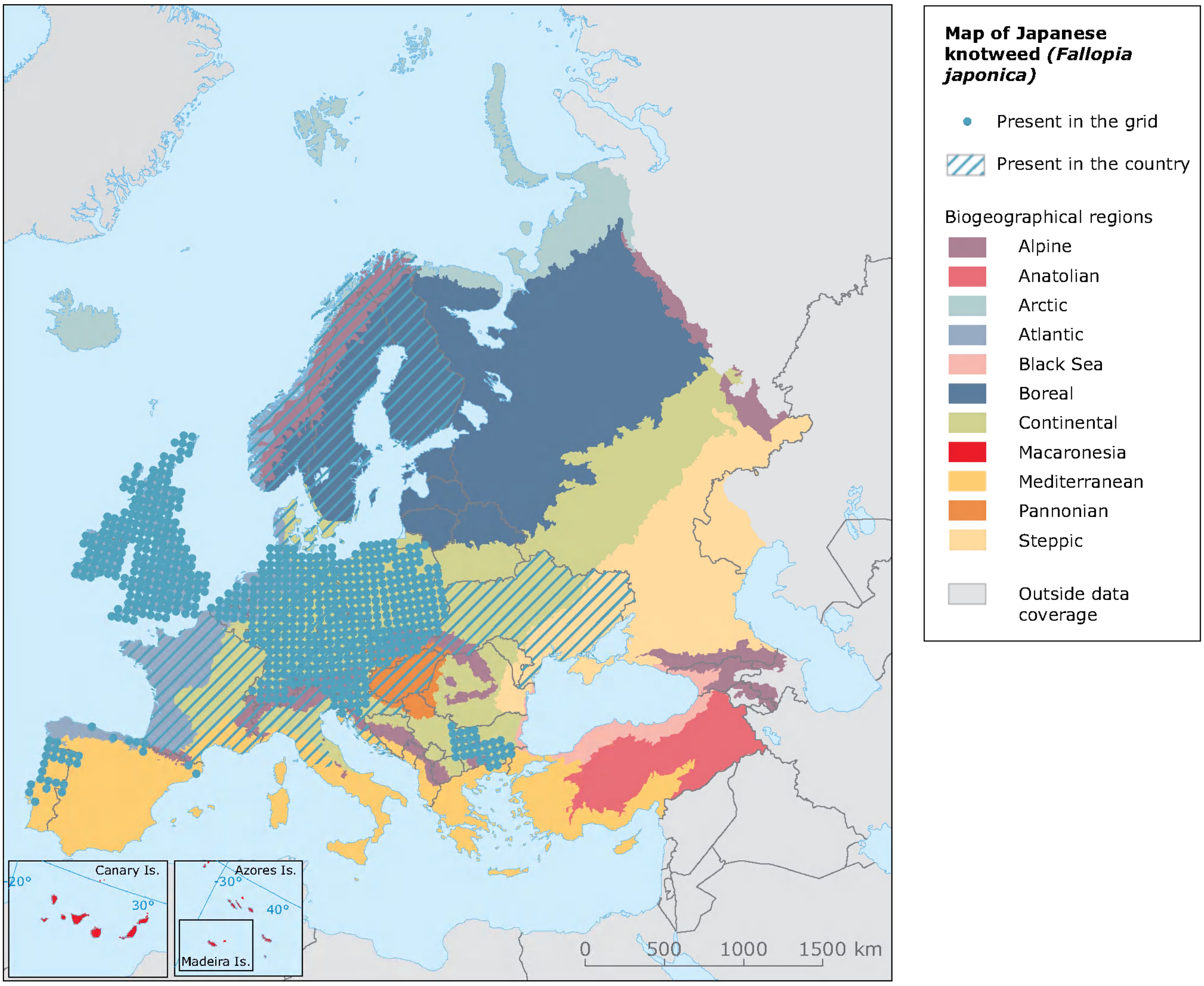
Japanese knotweed negatively affects ecosystems supporting (habitat) services by transforming species diversity and physico-chemical properties

(6) Supporting services are those necessary for the production of all other ecosystem services.

and the structure of invaded sites. By building up large and dense monodominant stands it reduces light availability to the understorey, inhibiting growth of woody seedlings and shading out other plants, which results in a delayed succession. In Europe, dense stands that cover more than 1 000 m^2 are known. Exclusion of accompanying species is supported by allelochemicals that negatively affect other plant species. Out-competing native plant species also has negative impacts on specialised insect species, when their host plants are replaced. A recent study showed that invaded habitats support lower plant and invertebrate species richness, abundance and biomass compared to uninvaded sites. These changes translate to higher trophic levels, as a knock-on effect was observed up the food chain. Invaded sites appear to be less suitable habitats for frogs, probably due to reduced invertebrate populations.

By not fully understood processes, the soil nutrient composition changes, affecting soil environment (increased organic material, water content, nutrient levels). Few herbivores feed on knotweeds in their introduced range, which contributes to its invasion success. Litter accumulates and leaf-litter dwelling invertebrate communities change: while abundance and diversity in snails and isopods decrease, predatory species profit from the simplified vegetation structure and increase. This means that invaded sites experience a shift from a plant-based to a detritus-based food chain.

Map of Japanese knotweed (*Fallopia japonica*)



Source: Based on Winter and Pergl, 2008a.

Japanese knotweed can negatively affect also ecosystems provisioning services. The rhizome system of knotweeds can seriously damage infrastructure, such as buildings (including archaeological sites), river bank stabilisations and water channels, railway tracks and roads, and construction land. By disrupting the integrity of flood defence structures, the risk of flooding is increased. Because aboveground plant parts die off after first frosts, monodominant stands leave open grounds and provide increased danger to erosion. In the United Kindgom, more than EUR 175 million is spent annually to control Japanese knotweed.

Japanese knotweed is used as ornamental plant and in folk medicine, young shoots are consumed in Asia and North America, and secondary compounds are of pharmaceutical relevance and a product from the Sachalin knotweed is sold as fungicide for plant protection. It was also successfully tested for decontamination of heavy metal-polluted soils. Because of its vigorous growth, cultivars of Japanese knotweed are considered as suitable for biofuel production. However, this may even further enhance its invasion.

Distribution and pathways

Japanese knotweed is native to East Asia (southwest China, Japan, Korea, Taiwan and Vietnam) and was introduced to Europe in the 19th century as an ornamental garden plant. It was widely planted in parks and gardens and also used as a forage plant and for erosion control. It was also introduced to Asia, Australia, North America and New Zealand. Today, it is widely distributed across Europe, except for south Europe, where it is still rare. Dispersal mainly occurs by rhizome fragments that easily break off, and which can produce new plants starting even from a few centimetres in size. Rhizomes are transported downstream by running water or translocated with contaminated soil over larger distances.

Management

Knotweeds are tough to manage; particularly, the extensive rhizome system makes removal by excavation extremely difficult. Regular mowing (up to six times per year) is necessary, but only weakens the plant and is not sufficient to achieve complete eradication. If possible, grazing can be enforced in addition to other management techniques. It is particularly relevant to burn or deposit the cutting material at appropriate sites because of the high regenerative capacity of even tiny fragments of knotweed rhizomes that can easily start a new infestation. This is why mulching or private composting of knotweeds should be avoided and disposal is restricted by law in some countries. Commercial composting is possible, but expensive. Chemical control with herbicides (e.g. application of glyphosphates on cut stems) is possible and successful, but not appropriate in certain habitats that are adjacent to water bodies. A combination of mechanical and chemical methods usually yields the best results. Recently, the United Kingdom started a field trial with a specific herbivore, a Japanese psyllid insect, as biocontrol agent. Because of the high regenerative powers, continuing on-site monitoring is necessary for several years.

Impacts of IAS on ecosystem services — interfering with supporting services ([7])

Ice plant *Carpobrotus edulis*

The ice plant

Species description

Ice plant is a perennial succulent that forms flat, large and dense mats. It has large and showy yellow flowers that fade into pink or purple. It can reproduce both vegetatively and by seed. It produces several hundred seeds per fruit that stay viable in the soil for two years, but also in fruits, constituting a soil and a canopy seed bank. Seed density may exceed 1 000 seeds per m^2. Vegetative propagation by runners, which root at nodes, is frequent so dense clonal mats are formed. Ice plant stems are up to 3 m long, shoot segments can grow 0.5–1 m per year with individual clones reaching 50 m in diameter. It is pollinated by generalist insect pollinators. Ice plant is well adapted to Mediterranean climates around the world, resistant to drought and saline conditions because of the succulent leaves, but intolerant of frost and therefore not occurring far inland or at higher elevations. It grows on coastal dunes and in sand habitats, coastal scrub, on rock cliffs and shores, the littoral zone of inland water bodies, salt marshes, and along roadsides and railways.

There is some controversy about the taxonomic identity of ice plants in Europe, because there is another introduced ice plant species (namely *Carpobrotus acinaciformis*) from South Africa occurring in Europe. *Carpobrotus edulis* is less widespread, but both 'species' hybridise and form a hybrid complex with intermediate characters. Introgressive hybridisation may result in the propagation of advantageous genotypes, including the possibility of passing genes from the widespread ice plant species to the rare one, turning this one

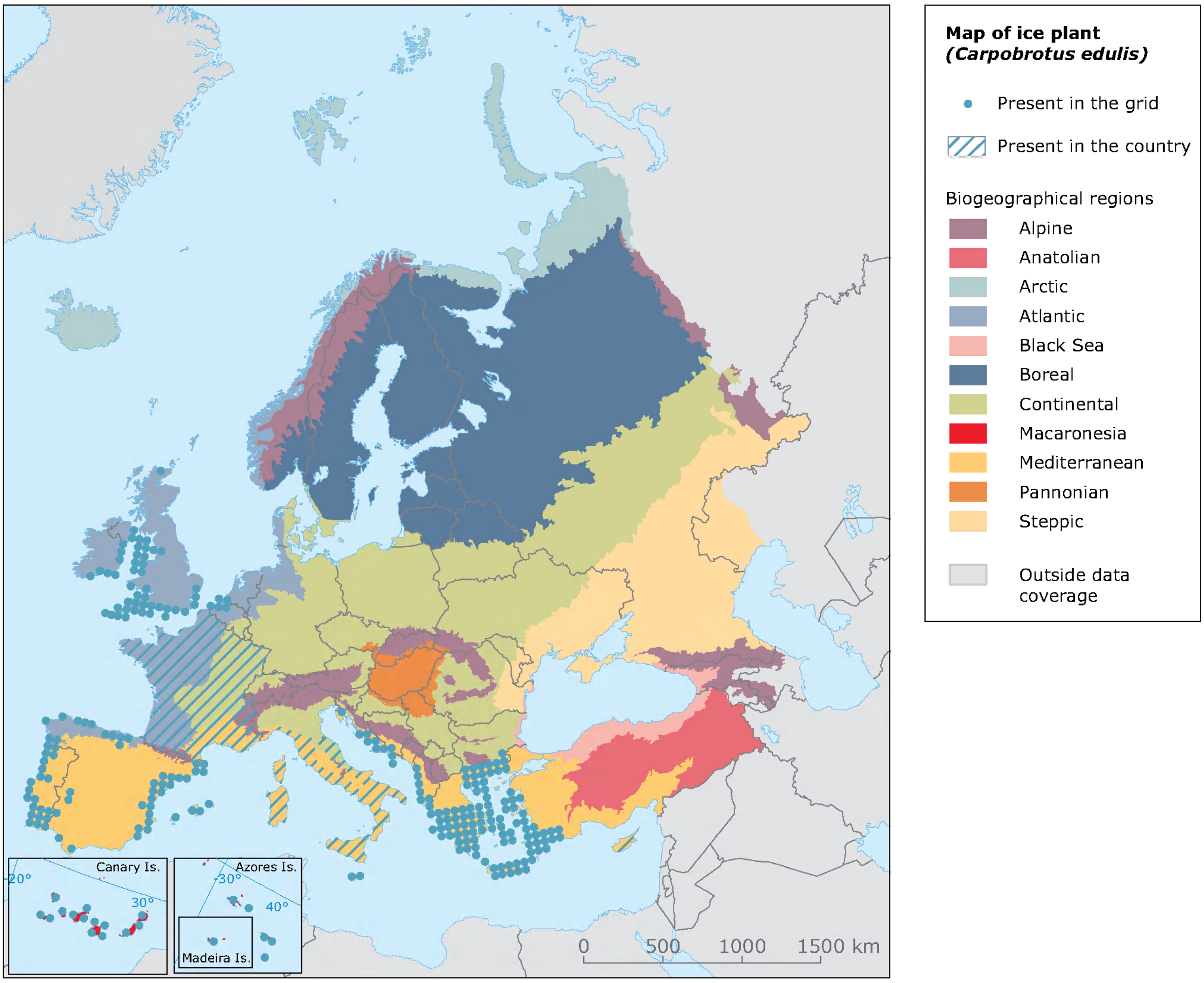
([7]) Supporting services are those necessary for the production of all other ecosystem services.

into a highly invasive species as well. The high genetic diversity found in ice plants supports high adaptability and may contribute to the continued invasion of both 'species'.

Impacts

Ice plants are known to have a major impact on ecosystems supporting (habitat) services as a consequence of the growth of dense, impenetrable and monodominant mats which may cover large areas, reducing local biodiversity by direct competition with native and often endangered coastal plant species. Ice plants compete for nutrients, water, light and space and can suppress the growth of native seedlings and mature shrubs, but also reduce bryophyte and lichen cover. An approximate decrease of 30–50 % in the diversity of native vegetation was reported. In mainland Spain and on the Balearic Islands endemic plants are threatened by competition from ice plants and in Portugal natural succession of sand dunes is affected. Soil carbon and nitrogen content increases and pH decreases at sites invaded by ice plants, largely due to litter accumulation by this species, and because secondary compounds reduce decomposition rates. This build-up of organic matter leads to a change in succession processes of dune communities. Hybridisation of ice plant varieties in Europe is frequently observed and hybrids apparently show greater vigour and higher invasion potential than their parents. Similar phenomena have been observed in other alien hybrid plants (e.g. knotweed species).

Map of ice plant (*Carpobrotus edulis*)



Source: Based on Winter and Pergl, 2008b.

Aside from its use as an ornamental plant in gardens and for landscaping along highways, ice plant is used to control erosion and stabilise sand dunes or embankments. It is also used as a medicinal plant, because its secondary compounds act antibacterial and fungicidal. The edible fruits are used as jam.

Distribution and pathways

Ice plant is native to the Cape Region of South Africa. It was introduced to Europe as an ornamental plant around 1680 and is now widely distributed on the British Overseas Territory of St. Helena and along the southern and western coastlines of Europe, the Mediterranean, North and South America, and the Pacific. The fruits are eaten by small mammals and the seeds dispersed via defecation after ingestion (endozoochory). Seeds germination is enhanced during this process. Fruits are eaten and seeds dispersed both by native and introduced mammals (rabbits, rats), which in some localities cause a mutualistic benefit, facilitating different invading species. It may be unintentionally translocated via small branches of plants during construction works as any shoot segment can produce roots or by birds using fragments as nesting material, but the major pathway is intentional introduction as an ornamental or landscaping plant.

Management

Mechanical control by hand-pulling or mulching with machineries and below-ground stem removal is effective, although laborious and needs to consider minimum site disturbance and maximum soil protection. Because of its high regenerative capacity — the plant can grow roots and shoots from any node — it is necessary to remove all plant parts to prevent reinfestation of the managed site. Obviously, monitoring and maintenance after taking action at sites is required. Grazing seems inappropriate as the salty leaves are disliked by most animals. Chemical control with herbicides is possible, but needs careful application to avoid non-target effects. Biological control has not yet been considered. Scale insects may be worthwhile candidates, but this needs more research.

Impacts of IAS on ecosystem services — interfering with provisioning services (8)

Pontic rhododendron *Rhododendron ponticum*

The Pontic rhododendron

© Photo courtesy of Katharina Dehnen-Schmutz

Species description

Pontic rhododendron is an evergreen compact shrub that can grow up to 5–8 m in height. It has dense branches and its colourful flowers are insect-pollinated. Between 3 000 and 7 000 small seeds are produced within a woody capsule that can persist for a few years. One bush can produce more than one million seeds per year. Several cultural varieties are known with different colours of flowers and shapes of leaves. It has also been widely used in the past as rootstock onto which other rhododendrons were grafted; however, roots are able to overtake the intended grafted species.

It tolerates different environmental conditions and can adapt to various habitats in the introduced range from deciduous and evergreen forests, to managed woodlands, peat- and heathlands, and urban areas. It avoids dry sites and prefers humid climates.

Impacts

Pontic rhododendron is very competitive and shades out plants wherever it grows, except for those trees that have grown above the rhododendron canopy. Seedlings of these trees, however, cannot establish beneath rhododendron and so in the long term forests are transformed to monodominant rhododendron stands. Leaves contain toxic chemicals, which protect the plant from herbivores and exude phenolic compounds that may inhibit the growth of surrounding vegetation. The plant

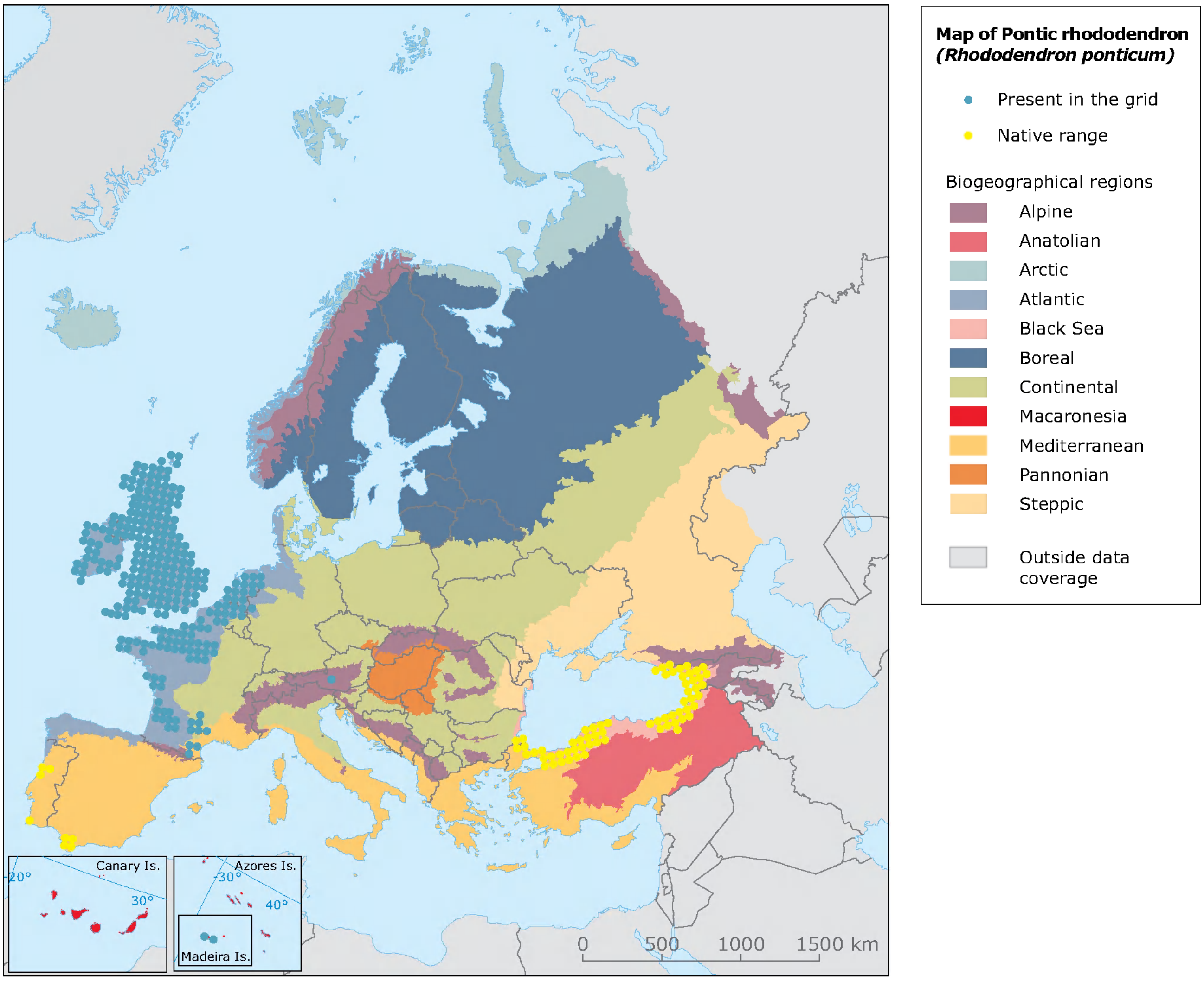
(8) Provisioning services refer to the products obtained from ecosystems.

is poisonous for animals (except for the seedlings) and mortalities of sheep have been reported. Pontic rhododendron is also a vector of pathogens that can cause diseases to oaks and other trees. It is the most important host for Sudden Oak Death that threatens trees, woodland ecosystems and other habitats. In Great Britain, it has played a key role in disease transmission into the natural and seminatural environments and its subsequent spread.

Pontic rhododendron is considered the most damaging alien plant in semi-natural habitats in the United Kingdom, with high management, control and restoration costs. Particularly, within oakwoods of Scotland and Wales and heathlands on acid soils of southern England, native species are displaced, diversity is reduced and species composition is changed. Stands growing along streams have been found to disrupt food webs by degrading community structures with reduced invertebrate abundance and suppressed algal production. On the Island of Lundy, the habitat of an endemic plant was overgrown by Pontic rhododendron. Furthermore, Pontic rhododendron has negative impacts on landscape aesthetics, tourism (through overgrowing of footpaths and rides) and forestry and causes loss of grazing land and serves as reservoir for the tree pathogens.

Pontic rhododendron also alters regulating ecosystem services, such as water retention, and provisioning services, such as timber production.

Map of Pontic rhododendron (*Rhododendron ponticum*)



Source: Based on Winter and Pergl, 2008c.

Distribution and pathways

Pontic rhododendron has a disjunct distribution including two widely separated subspecies: the subspecies *ponticum*, that is native to parts of southern Asia, the southern and eastern coast of the Black Sea, the Caucasus and Lebanon and the subspecies *baeticum*, that is native to southern Andalusia and the west coast of Portugal. It was introduced to the United Kingdom (according to molecular studies from Iberia) as an ornamental plant for gardens and parks in 1763, escaped and became established; it is also established in Belgium, France, Ireland, the Netherlands and Madeira, and locally in Austria, Norway, Poland and Slovakia. It has to be mentioned that the United Kingdom populations are genetically, ecologically and morphologically distinct from other populations due to hybridisation with other non-native rhododendron species originating from North America, with the purpose of selecting for a better adapted variety to the climate in Britain (this was also confirmed by molecular data). Pontic rhododendron was also introduced to New Zealand, where it is established in the wild since 1958 and is considered invasive.

Pontic rhododendron is continuously used and sold as an ornamental plant in Europe and its further spread is to be expected. It has also been planted by hunters as cover for game animals from where it invades into woodlands.

Natural dispersal occurs via seeds rarely over distances greater than 100 m by wind and water. Vegetative reproduction is of minor importance for dispersal.

Management

Because of its toxic compounds, adult plants are unpalatable to most herbivores and grazing therefore is not a viable management option. It has however been shown that sheep seem to graze the seedlings and have prevented establishment in some areas. Mechanical control by cutting needs laborious control for sprouting during the following growing season. If possible, it should be accompanied by mechanical removal or burning of root material. Because of possible re-colonisation from the seedbank, regular monitoring of sites is necessary after action is taken. Chemical control with herbicides is difficult due to the rough surface of the leaves, but glyphosate injections into root stumps combined with mechanical clearing provide good results. Biocontrol agents are not yet available.

Impacts of IAS on ecosystem services — interfering with provisioning services (9)

Spanish slug *Arion vulgaris*

The Spanish slug

Species description

The Spanish slug is a uniformly brown to reddish coloured slug that can reach between 7 and 15 cm adult body size. Because it has no shell which protects it from unfavourable weather conditions, it prefers moist days and the night hours for its activities. Unambiguous separation of adults from other slugs within the genus is difficult and requires dissection and investigation of male genitalia or genetic analyses. Juveniles can be separated from similar species by their characteristic brown colouration and two dark lateral bands. It is a hermaphroditic species, which means that each individual acts as male and female during mating. Each slug can lay up to 400 eggs and the young emerge after 3 to 5 weeks. They grow and live for one year and usually die in autumn after reproduction. The population size can vary substantially between years depending on temperature and rainfall. Young slugs hibernate in earthworm burrows, compost and soil litter. It is predominantly recorded from man-made, cultivated habitats, such as gardens and agricultural landscapes, but it is also found in natural and near-natural alluvial and riverine forests. In the Alps it has been found at up to 1 700 m altitude and in Scandinavia it occurs north of the Polar Circle.

Impacts

The main impact of the Spanish slug is on provisioning ecosystem services: it feeds on horticultural plants in private kitchen and vegetable gardens and in agricultural fields (mainly oilseed rape, maize and sunflowers). More than 100 different host plants have been observed. In Norway, more than 50 % yield loss in strawberry fields is reported. It can reach very high densities above 100 animals per square metre, which really annoys people and forces them to withdraw

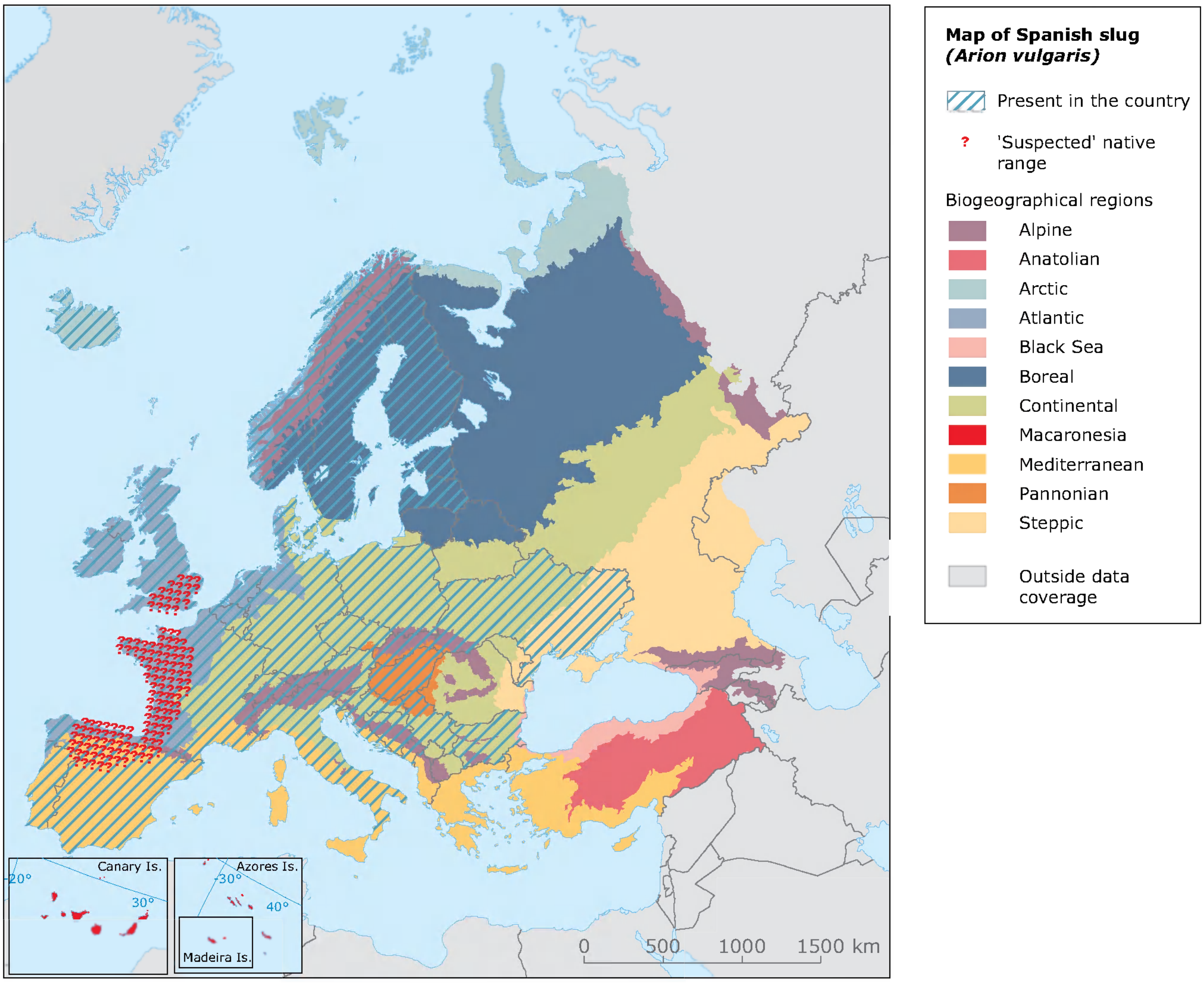
(9) Provisioning services refer to the products obtained from ecosystems.

their gardening activities. Spanish slugs feed on all above-ground parts of plants. Although they prefer fresh green plant material, they also feed on carrion and cannibalism is often reported. The slug is usually found in man-made habitats (gardens in urban and rural areas, agricultural fields), but after increasing in population size it is also increasingly reported from natural alluvial and riverine forests and other natural habitats that suit its requirements. In natural habitats, the slug is of biodiversity concern, because it predates, out-competes and hybridises with native slugs of closely related species. It also has a significant effect on plant species diversity changing the successional change. There are no positive effects of this slug species reported in the introduced range.

Distribution and pathways

Unfortunately, due to a misidentification when it was first discovered in Central Europe, the Spanish slug is often wrongly named in the public and scientific literature. The 'real' Iberian slug (*Arion lusitanicus*) is an endemic species, home to the Serra da Arrábida west of Setúbal in Portugal, where it lives a secret life within a small range. The correct scientific name of the introduced and invasive Spanish slug in Europe is *Arion vulgaris*, but its area of origin is unknown. It is believed to be native to the west of France and maybe to the north of Spain, although no reliable records are known from Spain. It is further unclear if it is native or alien to the south-east of Great Britain. It appears that the Spanish slug is in fact a French slug.

Map of Spanish slug (*Arion vulgaris*)



Source: Based on Rabitsch, 2008.

It was first found outside its suspected native range in 1955 in Switzerland. In the following decades it appeared in different regions across Europe without showing a clear pattern of expansion, which indicates that it was introduced repeatedly with different sources and presumably with different vectors. The most common pathways seem to be unintentional translocation of eggs and young slugs as contaminants of soil, horticultural (and maybe ornamental) plants and compost, and as stowaways with packing materials and gardening equipment. Today it is widely distributed in Europe and further spreading east, where the invasion front is not exactly known.

Management

There are several control techniques available. The most efficient seem to be mechanical control, collecting the species by hand and killing them with boiling water, deep-freezing or cutting with pruning shears or a knife. Mechanical barriers (slug fences) are also used. If gardens are managed 'biologically', a high number of natural predators (e.g. ground beetles, hedgehogs, some birds) can help regulate the slug population. In some countries, running geese can be rented for control. Environmental control by well directed watering of garden plants in the morning instead of using unspecific irrigation in the evening, and pronging the soil after the first freezing days in autumn and before the last freezing days in spring (egg batches are excavated from soil and die off) supports keeping slug numbers low. Chemical control with snail baits poisoned with molluscicides is available, but unspecific towards other snail and slug species and often even toxic for dogs and humans. Biological control techniques with nematodes are under investigation, but not yet applied widely.

Impacts of IAS on ecosystem services — interfering with regulating services (10)

Water hyacinth ***Eichhornia crassipes***

The water hyacinth

© Photo courtesy of Giuseppe Brundu

Species description

Water hyacinth is a free-floating, perennial aquatic plant, which consists of several shoots, each with up to 10 leaves. Roots develop at the base of each leaf, 20–60 cm long, sometimes up to 300 cm, constituting up to 60 % of the biomass. It has an enormous reproductive capacity: it flowers over 2 weeks and more than 3 000 seeds per year are released into the water. Seeds are long-lived, up to 20 years, and after germination in the new habitat it can flower again within 3 months. Seeds are not viable at all sites, but water hyacinth can colonise new areas through vegetative reproduction. After establishment the population increases quickly by vegetative propagation of horizontally growing stolons. Theoretically, a single plant can produce up to 140 million offspring each year and population size may double in 6 to 18 days. Water hyacinth lives in all nutrient-rich freshwater bodies, from ephemeral pools to natural and artificial lakes and slow flowing rivers. It is a generalist species that tolerates wide environmental conditions. However, it is sensitive to cold water temperatures and although rhizomes can withstand frost, long periods of cold weather lead to mortality. Regeneration from the seed bank is frequently observed and populations do not disappear after a cold weather event. It does not tolerate salinity above 1.6 %, which limits its distribution to freshwater habitats.

Impacts

The high abundance of the plant causes roots to intertwine and creates large floating mats, beneath which ecosystem conditions change drastically. This kind of canopy roof at the water's surface inhibits light penetration and decreases photosynthetic activity and abundance of phytoplankton. This decrease reduces algal primary production, increases water clarity and decreases oxygen levels. Predatory zooplankton and consequently fish come across reduced food supply and their abundance often decreases. Floating mats may also limit access to breeding and nursery grounds for some fish species and fish stocks are often reduced to the detriment of local fisheries. Natural vegetation is completely eliminated or strongly reduced at sites infested with water hyacinth. Changes in the aquatic ecosystem can encroach into the terrestrial world, because distributions and behaviours of water birds are also affected by the dense floating mats. Water hyacinth alters food web structure and energy flow in aquatic ecosystems; when plants die and sink, decomposition may lead to lower oxygen levels in the water column and increase sedimentation. By storing nutrients it also affects nutrient and biogeochemical cycles in the water body. The high evapotranspiration rate of the plant leads to indirect negative ecological and socio-economic effects in dry regions, because of the high water demand; the dense mats interfere with water body usage

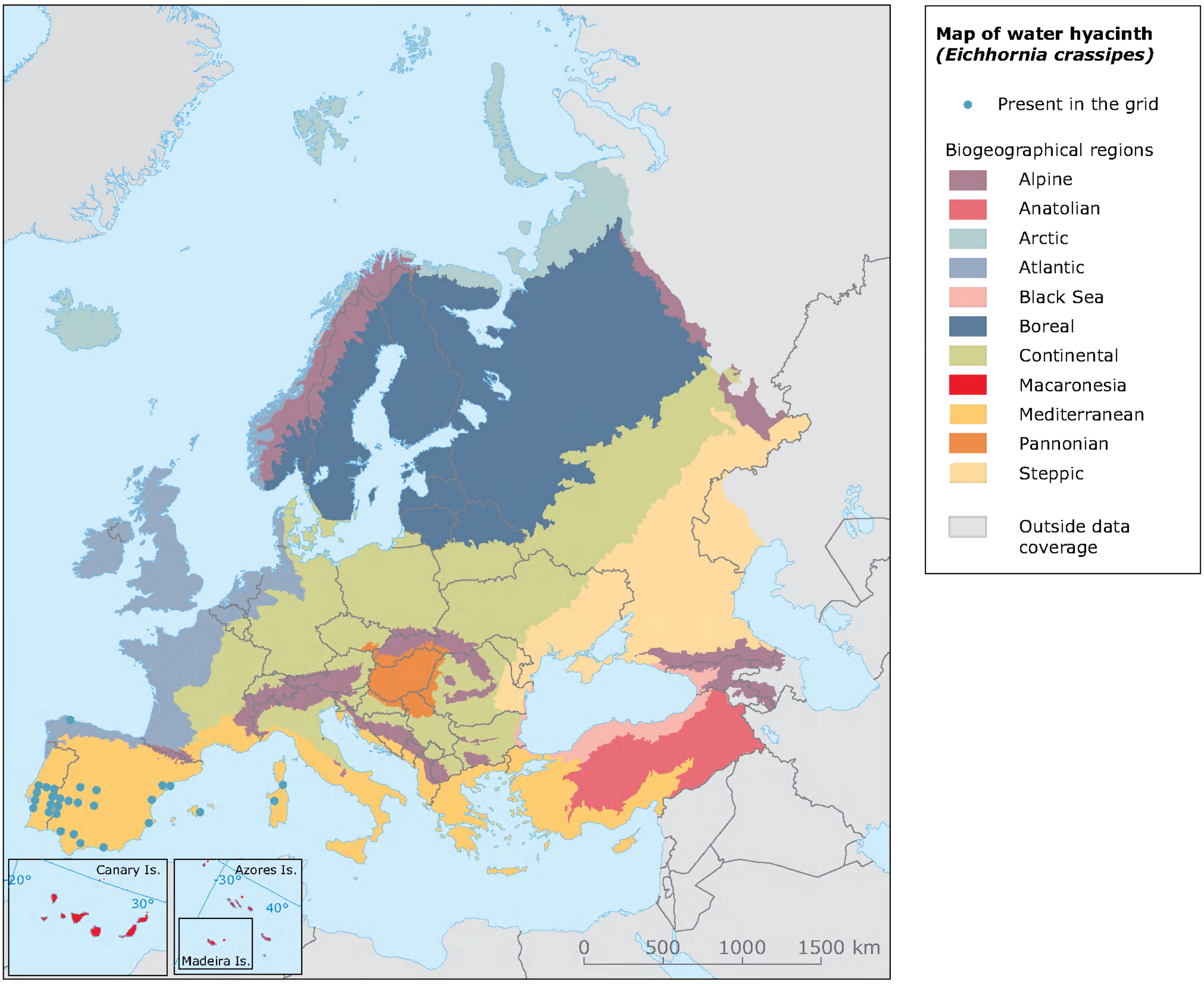
(10) Regulating services are benefits supplied by self-maintenance properties of ecosystems.

(ship navigation, restricted access to the water for recreation and fisheries, recreation, tourism and real estate values, hydropower stations) if waterways are blocked or water pipes clogged thus disrupting socio-economic and subsistence activities. Floating mats of water hyacinth further support organisms that are detrimental to human health as being vectors of diseases, for example mosquitoes and snails. It has a negative impact on rice production by directly suppressing the crop plants, inhibiting rice germination and interfering with harvesting. It was also reported to be an alternative host plant for the Asian corn borer and the rice root nematode.

Some invertebrate and algae species profit from the changed environmental conditions as the floating mats provide substrate for colonisation of epiphytic organisms, food resource for some species and shelter for juvenile fish from predators and spawning ground. Water hyacinth accumulates pollutants and may be used for decontamination and wastewater treatment, and it is also used as a vegetable in East Asia, for handcrafts, animal feed and fertiliser in East Africa. Because of its fast growth it is also considered as a bioenergy plant.

Costs in China were estimated to amount around EUR 1 billion per year, and to several million per year locally in different regions (e.g. Lake Victoria, Nile, Panama Canal). Management costs to remove 200 000 tonnes of the plant along 75 km in the Guadiana river at the Portuguese-Spanish border amounted to EUR 14 680 000 between 2005 and 2008.

Map of water hyacinth (*Eichhornia crassipes*)



Source: Based on EPPO, 2008a.

Distribution and pathways

Water hyacinth is native to the Amazon basin and has been introduced to tropical and subtropical regions around the world as an ornamental plant. In Europe it is established locally in the Azores, France, including Corsica, Italy, Portugal and Spain, and casual records are known from Belgium, the Czech Republic, Hungary, the Netherlands and Romania. It is often cultivated in public and private garden ponds, parks and botanical gardens.

Natural dispersal occurs by seeds (including dispersal by water birds), wind and water currents that transport plants. Extreme weather events may move seeds or plants over long distances or disconnected water bodies. Unintentional human transportation with boats and equipments was observed. Intentionally, the species is introduced as an ornamental plant.

Distribution seems to be limited by cold winter temperatures. It is expected that global warming provides increasing opportunities for establishment of this species in the introduced range.

Management

Different control methods are available, and usually a combination of these should be applied, depending on the local circumstances and intended use of the water bodies. However, eradication of established populations is extremely difficult and requires a long-term control programme including regular post-control monitoring. There is no example of successful eradication of water hyacinth anywhere in the world once the plant has established. Physical control includes the labour- and equipment-intensive manual removal of plants from the water bodies by mowing and cutting, although transport and disposal can be challenging as the wet weight per acre can reach 200 tonnes. Chemical control is executed applying herbicides, but may include significant non-target impacts. Biological control with two South American weevil beetles and the water hyacinth moth is successfully applied in many regions. The beetles feed on the leaves and cause the plants to sink. The water hyacinth moth is particularly effective against young plants. Environmental control by reducing the nutrient input into the water bodies is considered the most sustainable long-term management action, although the species nevertheless may establish in areas where nutrient level is low. Utilisation control, that is using the plant for different purposes, for example as fodder, biomass energy, fertiliser, and for waste water treatment, may be considered as an additional benefit of any control option.

Impacts of IAS on ecosystem services — interfering with regulating services [11]

Yellow-legged hornet *Vespa velutina*

The yellow-legged hornet

Species description

The yellow-legged hornet is a social wasp slightly smaller than the native European hornet, with a body length up to 3 cm in queens, and about 2.5 cm in workers. The head is black with an orange-yellow face. The body is dark brown or black velvety, bordered with a fine yellow band and a single abdominal segment almost entirely yellowy-orange, which makes it difficult to confuse with any other species. Like other social wasps, the colonies last one season, and only the fertilised queens survive the winter to found new nests after hibernation. Each colony, initiated by a single individual, can produce several thousands of workers, plus hundreds of males and new founders able to mate and subsequently produce new colonies. This efficient life-cycle initiated by only one individual makes social insects, such as hornets, redoubtable invaders. Nests, round or pear shaped from 50 to 80 cm in diameter, are usually made in tall trees in urban and rural areas, but are also found in garages, sheds, and very rarely in holes in walls or in the ground.

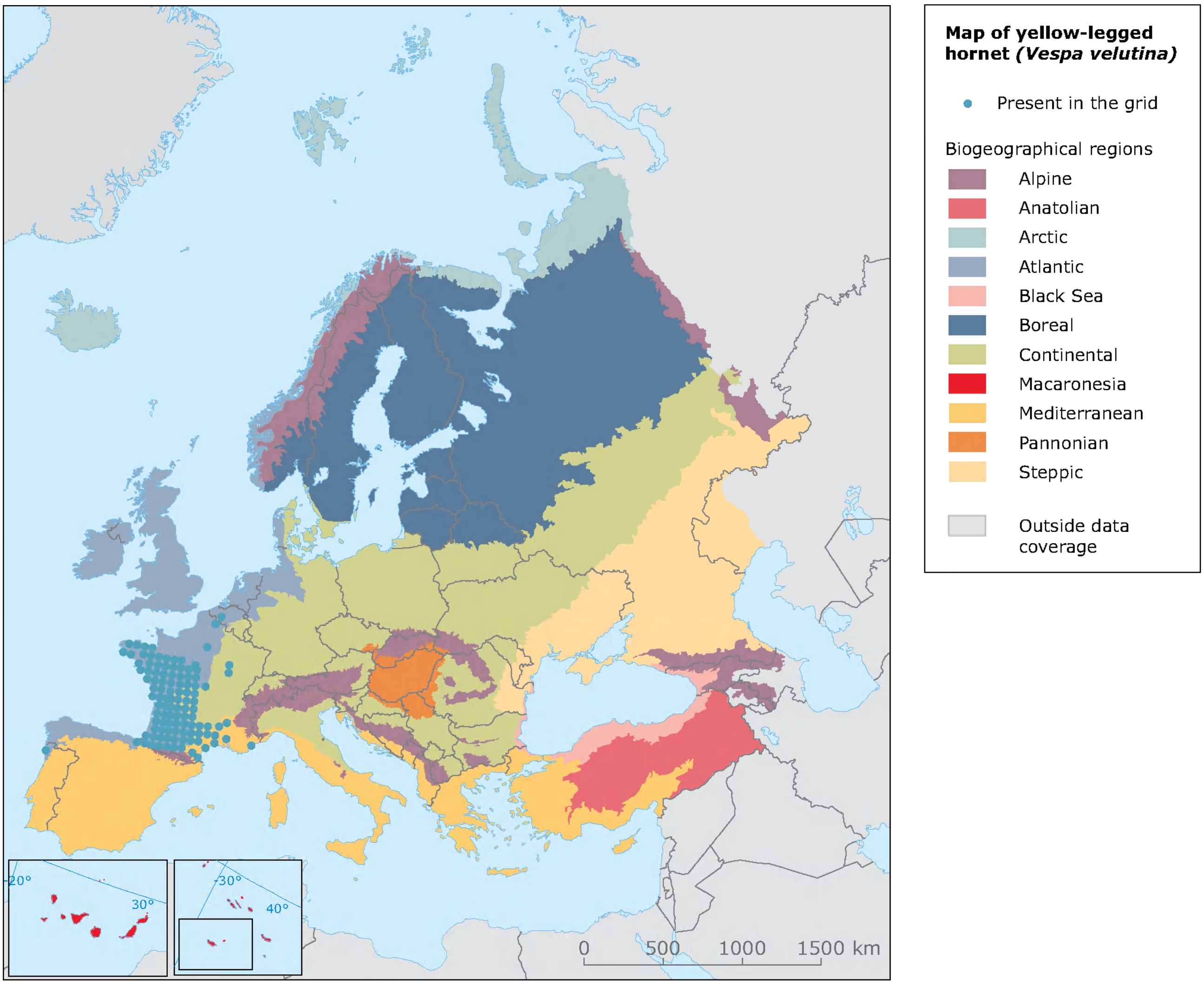
(11) Regulating services are benefits supplied by self-maintenance properties of ecosystems.

Impacts

The yellow-legged hornet is mainly a predator of social wasps and bees, but like the European hornet, it also consumes a wide variety of other insect preys. As a highly effective predator of honeybees and other beneficial insects, a number of vulnerable prey species, including many wild pollinators, may become threatened by this new predator. For this reason, the yellow-legged hornet may negatively affect ecosystems providing services, and particularly pollination. In fact, the yellow-legged hornet has shown a preference for social insects such as honeybees, common wasps as well as other pollinators, such as hoverflies, and necrophagous flies, such as carrion and house flies. The study of the prey spectrum of the hornet, as well as the huge size of its colonies, suggests that it could have a noticeable impact on local native insect biodiversity. Moreover, it can cause significant losses to bee colonies, other native species and potentially ecosystems. The hornet has a clear impact on bees but, even if difficult to demonstrate, its impact on wild insect species may be even more deleterious if considering that large colonies can produce up to 10 000 individuals in a season.

Honeybees are among the hornet's main preys, so the yellow-legged hornet is expected to have an economic impact on beekeeping activities. On the other hand, beekeeping activities have already been suffering a noteworthy decline under the pressure of other multiple factors, such as air pollution, climate change, the decline in flowering plants, fungal

Map of yellow-legged hornet (*Vespa velutina*)



Source: Based on Rome et al., 2011.

attack, parasites like the invasive alien *Varroa* mite, and pesticides. Reports of apiaries devastated by the yellow-legged hornet are thus causing growing concern among beekeepers, particularly in France. However, so far in France predation of honeybees by the yellow-legged hornet seems to be limited to the adults rather than the entire brood.

Although very occasionally, bees try to deter the yellow-legged hornet from predating them by 'shimmering'. Through this technique hundreds of bees produce a wave-like pattern across the nest by flipping upwards their abdomens and shaking them in unison. This phenomenon is either threatening or confusing to a hornet. Another way to try to withstand the attacks of the yellow-legged hornet is through 'heat-balling'. This remarkable defence, although not very efficient, is certainly spectacular, as it consists of a giant ball of bees piles suffocating or literally cooking the hornet alive by weighing the predator down while vibrating their wing muscles, thus greatly increasing the temperature inside the ball to about 45 °C.

The yellow-legged hornet is no more dangerous for humans than the European hornet as in general it is not aggressive. However, even if this species is not a direct threat to people, its large size, painful sting and noisy flight make it a very frightening insect. Moreover, it is possible that an increase and spread of the yellow-legged hornet, notably in urbanised areas, will raise the question of an increasing number of sting accidents. After all, even though hornets will not attack as long as the colonies remain undisturbed, stings may potentially cause a life threatening allergic reaction. Therefore, 'close encounters' with large nests, which are usually found on top of tall trees, should certainly be avoided.

Distribution and pathways

The native range of the yellow-legged hornet includes Afghanistan, Bhutan, China, India, Indonesia, Laos, Malaysia, Nepal, Pakistan, Thailand and Vietnam. The subspecies introduced to Europe, the yellow-legged hornet, is native to South-East Asia, particularly Bhutan, China and India. It was recorded in Europe for the first time in France in 2005, where it was probably introduced accidentally through the horticultural trade. It is thought that some hibernating queens arrived in France in a container of pottery from China before 2004, possibly through the port of Le Havre, in Normandy. The yellow-legged hornet spread very rapidly across south-western France (at around 100 km per year), and has recently reached northern Spain, Portugal and Belgium and is considered likely to arrive soon in Italy and Great Britain (where a specific response plan has just been developed). Invasion risk modelling suggests that this species could spread over a large part of Europe, with reduced risks in the dryer southern regions. It might well be introduced also in other areas of the world, since the scenario of introduction through international trade could certainly be repeated. It was also accidentally introduced into Korea in the 2000s.

Management

Research to develop an effective control method for yellow-legged hornets is still in progress. In general, uncontrolled mass trappings and colony destruction both inside and outside invaded areas, as it is performed in France, might be deleterious to many non-target insects. In fact, none of the traps currently being used show selectivity for yellow-legged hornets. For example, the use of toxic-bait is not sufficiently selective as it would be attractive for all species of wasps. Nonetheless, despite scientific advice, baited traps are generally regarded as the best means to control wasps and for this reason remains the most commonly used method. Since uncontrolled mass trapping induces side-effects on non-target species, this method should only be used to limit the impact of the yellow-legged hornet predation on apiaries. After all, the impact on honeybees can be limited by merely reducing the hive entrance to a narrow slit.

Destruction of colonies remains the best way to limit locally the impact of this hornet on bees and other insects. The most effective method for colony destruction is the injection of a poison into the nest with a telescopic perch, followed by the removal of the destroyed nests (with dead hornets inside) to avoid other animals being intoxicated by eating poisoned hornets.

Preventive trapping must be avoided, or performed only punctually to survey the yellow-legged hornet arrival in a given region and warn beekeepers as soon as possible that they should increase their vigilance.

Impacts of IAS on ecosystem services — interfering with cultural services ([12])

Killer shrimp *Dikerogammarus villosus*

The killer shrimp

Species description

The killer shrimp is a gammarid — a very small crustacean within the group of amphipods — characterised by a laterally compressed body (flattened from side to side), curled, semi-transparent and sometimes with a striped appearance. Its body length, which can be up to 30 mm from tip of tail to tip of head, is relatively large for a freshwater amphipod and in fact is considerably larger than all native gammarids. The mandibles are large and powerful, thus giving it a very effective mechanism for predation, and the first two pairs of walking legs are modified to assist with grasping of food. Females have extra branches located on the walking legs which create a space used to shelter and incubate eggs.

It can be distinguished from other gammarids by the tail features (e.g. the presence of cone-shaped protrusions). The killer shrimp is capable of adapting to a wide range of habitats in lakes, rivers and canals where it prefers still or flowing freshwater and brackish water, although it is able to adapt to a certain degree of salinity. In general, it prefers rocky substrates with crevices, but can colonise a wide variety of substrates (with the exception of sand and leaf litter) often among hard surfaces (cobble/pebble) or vegetation, for example all types of fastened banks, sheet-pile walls, and especially mats of algae near or on the water surface. The species exhibits a wide range of environmental tolerance being able to survive in damp conditions for up to five days, and can endure poor water quality as well as major fluctuations in temperature,

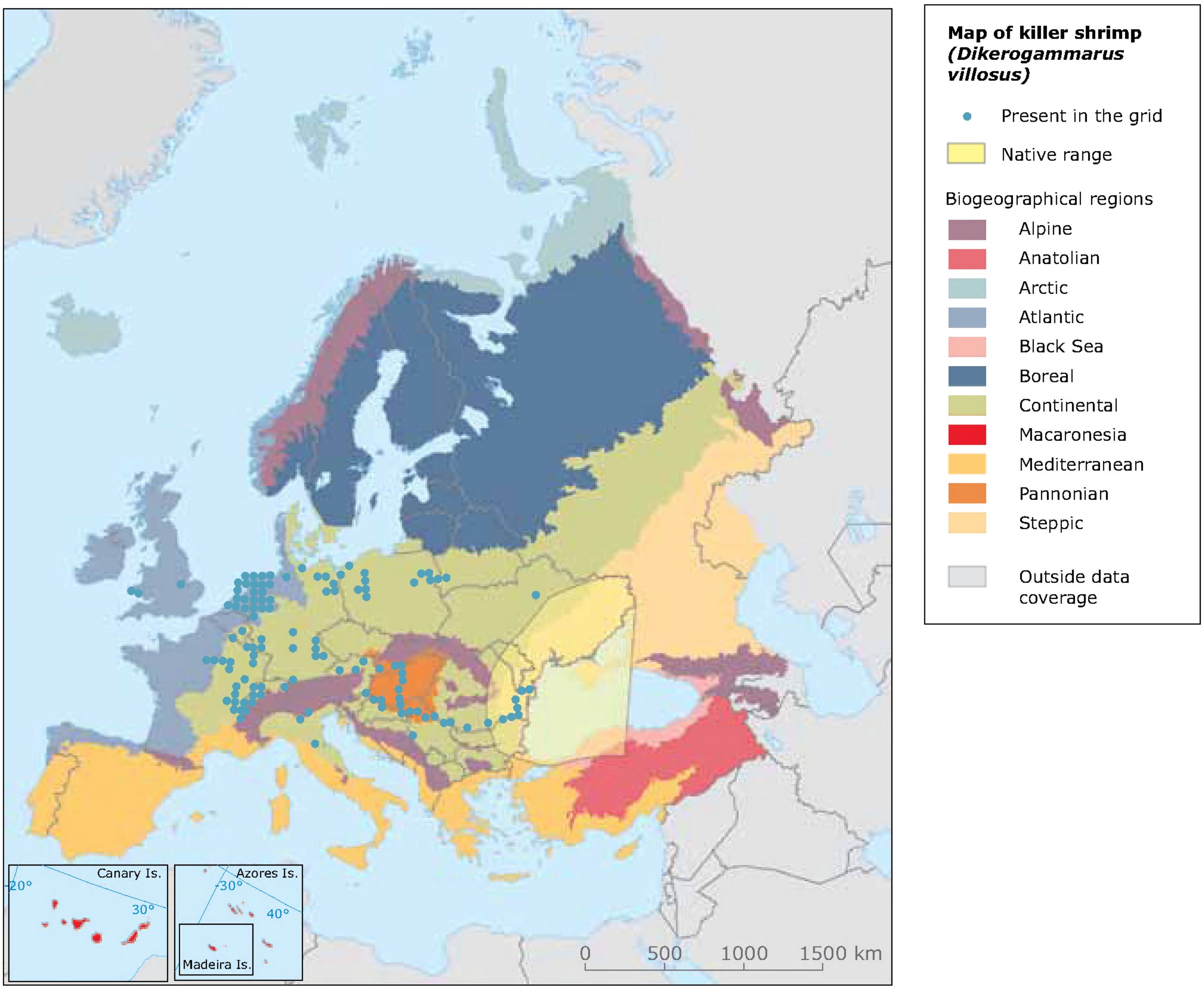
([12]) Cultural services generate non-material benefits derived from ecosystems.

salinity and oxygen levels. However, it is only present in areas with low current velocity.

Impacts

The killer shrimp may cause significant ecological disruption, including reduced biodiversity and local species extinction, through either direct predation, or through indirect cascading effects throughout different levels of the food web. The diet of this omnivorous predator includes a wide range of items, from macroalgae and microalgae (which are taken from cleaning stones and through filter feeding), to a variety of invertebrates such as mayflies, damselflies, leeches, chironomids, cladocera, isopods and snails, but also fast moving species, including other gammarids. Recent studies have shown that macroinvertebrate populations decline after the establishment of the killer shrimp. The killer shrimp is a much more deadly predator than native amphipods, partly due to its much larger and more powerful mouthparts. Not surprisingly it can locally eliminate other gammarid species also through competition (as a method of competitive removal it seems that macroinvertebrates are killed, but not eaten). Interactions between the killer shrimp and native gammarid species can result in displacement or local extinction of native species. For example a major impact could be the decline of leaf decomposition, which could have a dramatic effect on nutrient dynamics within the invaded ecosystem. In addition, the species has been also observed eating fish eggs and fish fry or attacking small fishes, which

Map of killer shrimp (*Dikerogammarus villosus*)



Source: Based on Gallardo et al., 2012.

raises concern over whether vulnerable life stages of vertebrates (eggs, larvae and juveniles) may also be at risk.

Given its important invasive potential and ecological plasticity the killer shrimp can quickly dominate the invaded habitats and can significantly alter their ecology. Therefore, the greatest direct economic and social harm is likely to come from changes to fishery quality, and therefore a knock-on impact on recreational use of invaded water bodies. The killer shrimp may clearly have a major impact on ecosystems cultural services, and particularly on recreational activities like angling (besides affecting ecosystems supporting (habitat) services, of course). For example, recent observations in the invaded sites in the United Kingdom suggest that the species represents a key prey item of trout and perch. This could result in diet shift in a number of fish species, with a consequent change in distribution of fish communities and a change in fish catchability for anglers. Moreover, the killer shrimp may serve as intermediate host for acanthocephalan parasites, which may infect trout and other salmonids and can thus have deleterious impacts on fisheries.

Recent studies have shown that the killer shrimp is very strongly linked with the invasive zebra mussel, with which it is thought to have co-evolved. Together with the zebra mussel it has invaded many freshwater ecosystems, with severe consequences for entire communities and other invertebrates, as they seem to take advantage of each other. For example, the killer shrimp can clearly increase in abundance in the presence of this invasive mollusc, probably because the latter may provide important habitats through the production of byssus threads and shells and food material through biodeposition of detritus.

Distribution and pathways

The killer shrimp is native to the region of the Caspian and Black seas (it is widely distributed in the Danubian basin and Lake Balaton). It has rapidly spread across Europe following the opening of the Rhine-Main-Danube canal in 1992, which connected the shrimp's home waters to western Europe's waterways. As a consequence the species is now present in many countries including Austria, Belgium, the Czech Republic, France, Germany, Hungary, the Netherlands and Switzerland. A few populations were recently introduced to Italy and the United Kingdom. The colonisation of most European hydrosystems probably occurred through the Danube and Rhine Rivers' corridors, the most likely introduction vector being shipping through ballast water and hull fouling of vessels. As a remark, along the Rhine it was able to spread downstream at a speed of 124 km per year. Otherwise, it is likely that its spread is facilitated by people, for example through the movement of angling gear, nets, boats, kayaks and trailers between water bodies, but also by shipping activity, aquaculture, and possibly by some kind of habitat alteration caused by the previous introduction of the zebra mussel.

Management

A key strategy should normally focus on prevention. Containment procedures should be employed together with standard cleaning and inspection procedure and the implementation of stringent regulations including surveillance activities, which would maximise the opportunities for containment and eradication of newly established populations.

Biosecurity is critical to reduce the risk of spreading the species. As a key biosecurity measure, stakeholders should be strongly invited to reduce the risk of exposure to the shrimp (e.g. by avoiding areas where the shrimp is at its highest densities) and checking, cleaning and drying equipment before and after entering water bodies. Another key part of biosecurity is awareness-raising among water users. For example, in the United Kingdom a 'stop the spread (check, clean, dry)' campaign is being planned to try to raise awareness and change behaviour. This is a good example of a rapid response measure. On the other hand, a number of management options have been suggested, although they have never been attempted for this species and therefore have remained untested. Examples are the use of sodium hypochlorite, hot water, dewatering of a site, pyrethrin (Pyroblast), rotenone or other poisons (like BioBullets, which is also used for zebra mussels) but they are also likely to result in mortality to non-target species. Further research is being carried out into disinfectant methods. Other possible options include the increase of water salinity, or the use of porous house bricks to be deployed in the water colonised by the killer shrimps to provide refugia from which the species can be 'mopped-up' through regular lifting. Also the introduction of predators, such as the brown trout, may assist in localised control efforts. The biggest issue is what measures could be effective in eradicating the shrimp from such large water bodies while also being acceptable (e.g. in terms of regulated use of pesticides in water, public acceptability, etc.). Further research is being commissioned into what, if any, eradication methods might be feasible.

Impacts of IAS on ecosystem services — interfering with cultural services ([13])

Tree of heaven *Ailanthus altissima*

The tree of heaven

Species description

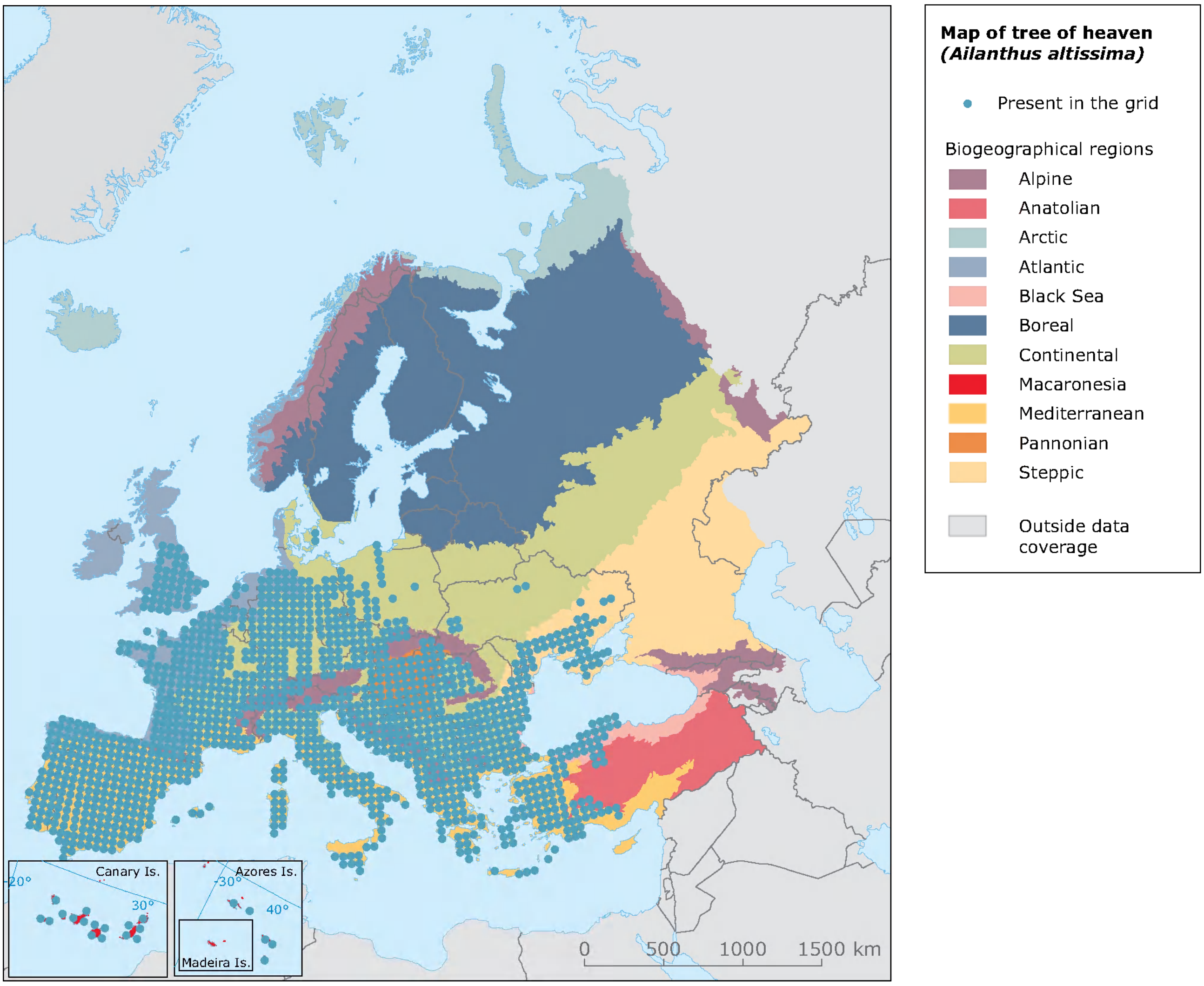
Tree of heaven is a medium-sized, short-lived early successional tree, reaching heights of 15 to 30 m and with a life span of not more than 100 years. Branching starts comparatively late, because energy is first invested into the root system and the main stem axis. Tree of heaven is one of the fastest growing trees, which allows monopolisation of resources (such as light) and results in monodominance at suitable sites. Particularly young plants can grow more than 2 m in height per year. It is a highly drought-resistant species, capable of surviving dry periods with its long root systems, which also enabled successful establishment on bare grounds in cities. It is a dioecious tree which means that there are male and female trees. Seed set usually starts at 3 to 5 years with highest fertility between 12 and 20 years of age. Tree of heaven is pollinated by several unspecialised nectar- and pollen-feeding insects and seeds are dispersed by wind. More than 325 000 diaspores are produced annually, which are dispersed by wind. In addition, vegetative regeneration by sprouts emerging from roots or the stem after disturbances, such as cutting or girdling, is very effective. This also provides dispersal opportunities, because shoot fragments can easily set adventitious shoots and roots.

([13]) Cultural services generate non-material benefits derived from ecosystems.

Impacts

Tree of heaven is a pioneer plant par excellence and grows on waste lands, but also in tiny gaps on abandoned buildings and in cracks in street pavements. It prefers disturbed urban and rural habitats. Due to its high stress-resistance it also survives along motorways and railroads, despite pollution or herbicide treatments. Growth close to buildings and at road embankments can cause serious economic costs due to damage to the infrastructure. In south Europe (Italy and Portugal) the extensive root system harms historic and archaeological buildings. From urban settings, it spreads to transportation corridors, such as railroad and motorway verges, but also to natural sites, such as dry forests, river banks and dry grassland. Colonisation of dry grassland and dry open forests is problematic due to its superior competitive abilities, which causes loss of native biodiversity. Most affected habitat types are Pannonian steppe formations, river bed vegetation, rocky outcrops and coastal zones of Mediterranean islands. Invaded sites on Mediterranean islands showed a decrease of 24 % in species richness compared to uninvaded sites. Competitive advantage is due to belowground dominance, toxic allelopathic compounds that also lead to a very low degree of herbivory. Tree of heaven further induces changes in soil chemistry, such as increasing total nitrogen and organic carbon content as well as soil pH. Negative effects on human health rarely occur, such as allergic reactions to pollen and dermatitis from sap contact.

Map of tree of heaven (*Ailanthus altissima*)



Source: Based on Kowarik, 2011; and Nentwig, 2011.

Positive effects include the decorative value and the substitution of particular ecosystem functions in urban green space. It is intentionally planted in windbreak hedges, to control erosion on slopes, and it is used as firewood and for paper production. In China it is used in folk medicine and its possibly wider pharmaceutical use is currently under investigation. A failed investment was its use as a host plant for silk production with the Ailanthus silk moth in the late 19th century in France and Italy.

Distribution and pathways

Tree of heaven is native to China, where it grows in mixed broadleaved forests. It was introduced to Europe in the 18th century for furniture purposes (which was not successful), and as an ornamental plant in parks and gardens, from which it has successfully invaded natural habitats. In Europe today it is established over large areas from the Iberian to the Krim Peninsula, being confined to warm lowlands and only rarely growing up to around 1 000 m altitude. Due to its high drought-resistance it is particularly successful in the Mediterranean and Pannonian region in Europe. Distribution is limited by cold winter temperatures (it is absent in northern and north-eastern Europe), indicating that climate warming is likely to support further spread northwards. It was introduced to all continents of the world except Antarctica and has an almost cosmopolitan distribution in urban habitats. Dispersal by clonal growth, wind and water drift of seeds enables local spread.

Management

Control of this vital species is cumbersome due to its high regenerative capacity, and it has to include different methods. To avoid root suckers emerging from root fragments and stump sprouting after cutting, girdling of single trees is recommended. The following year the vitality of the tree is reduced and cutting without invoking much sprouting is possible. Chemical control with different herbicides is possible depending on site-specific circumstances and should be combined with other management actions (e.g. hand pulling of young seedlings). A few biocontrol agents are in the test stage, but not yet employed in Europe. Due to the high regenerative powers of the tree, subsequent monitoring over some years is required.

Impacts of IAS on human health — disease vectors

Asian tiger mosquito ***Aedes albopictus***

The Asian tiger mosquito

Species description

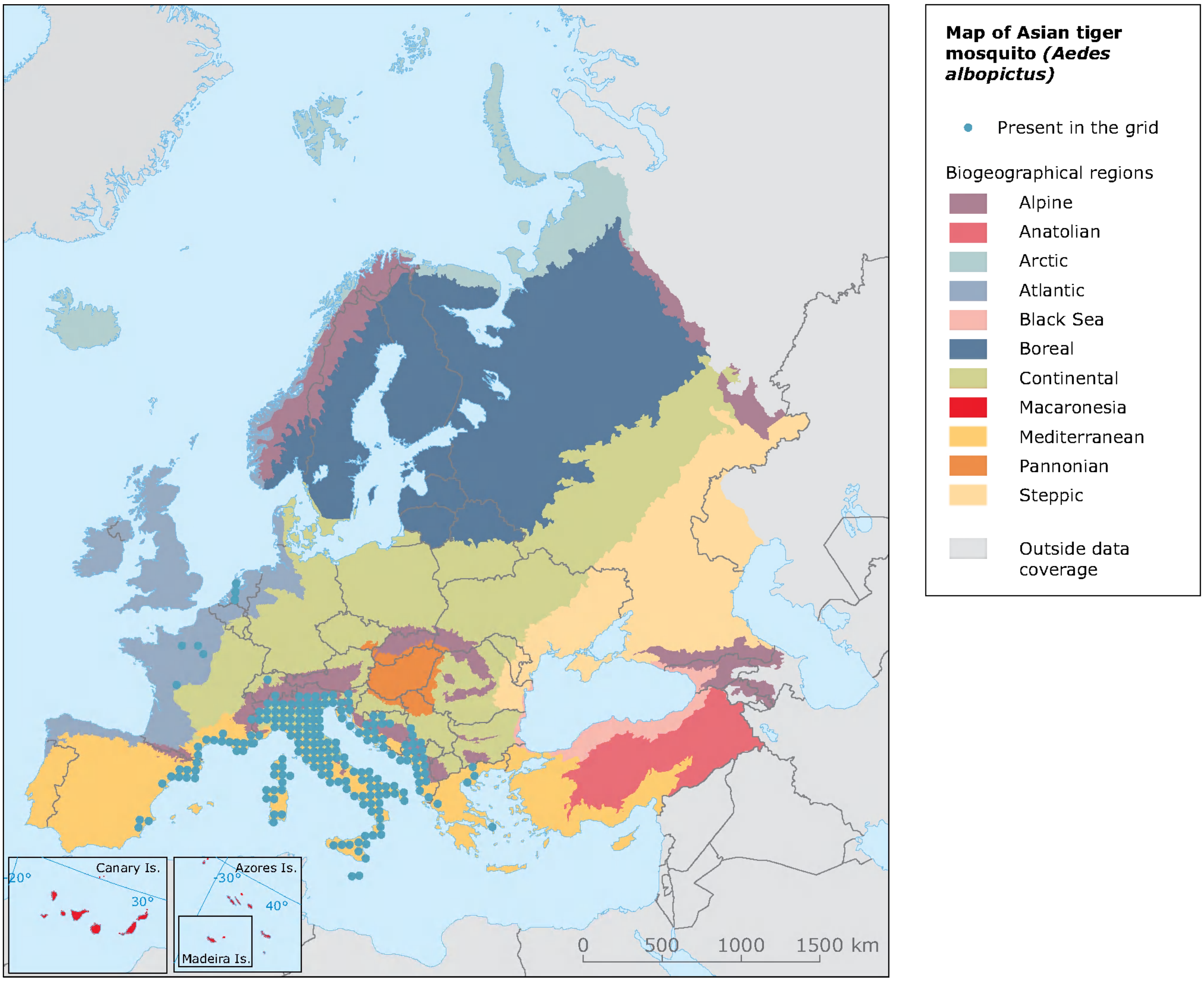
The Asian tiger mosquito owes its name to the very characteristic pattern of the black body with white stripes. Also down the length of the back there is a distinctive single white stripe. They are small, fragile insects with slender bodies, about 2–10 mm long. Like in other mosquitoes, adults obtain energy from feeding on plant juice. Otherwise females, to produce eggs, bite and feed on blood through an elongated proboscis. Although they bite primarily humans and other mammals, they accept blood from a wide variety of vertebrates, including birds, amphibians and reptiles. The Asian tiger mosquito mostly occurs in densely vegetated rural areas, agricultural areas, coastland, estuarine habitats, lakes, marine habitats, natural forests, planted forests, range/grasslands, ruderal/disturbed, scrub/shrublands, urban areas, water courses and wetlands. However, their ecological flexibility allows this species to colonise many types of man-made sites and urban regions.

The mosquito has three distinct developmental stages occurring in water, which consist of egg, larva and pupa. The females lay desiccation- and cold-resistant eggs above the water surface in tree holes, plant axils, bamboo stumps, tires or any other kind of artificial water-holding containers, where larvae can develop. Larvae can survive even in very small collections of water. For example, in urbanised areas, flower pots, bird baths, abandoned containers, tin cans, plastic buckets, water recipients and tires provide excellent opportunities for breeding as they can effectively collect and retain rain water for a long enough period of time if stored outdoors.

Impacts

The tiger mosquito is an aggressive daytime-biting insect associated with the transmission of more than 20 human pathogens. These include yellow fever, Rift Valley fever, chikungunya and sindbis (all of which are present in the Mediterranean) as well as dengue, West Nile and Japanese encephalitis viruses. The extent to which such diseases can be actually transmitted is unclear. However, currently there is solid evidence for its role in the transmission of two diseases: dengue and chikungunya. The small outbreak of chikungunya virus that developed in the north-eastern part of Italy during the summer of 2007 has clearly shown that the tiger mosquito is an important disease vector and may represent a true public health challenge. The outbreak in Italy was made possible by immigration of a single infected (but asymptomatic) man from India and the enormous population of tiger mosquitoes in the peninsula. Further evidence of the tiger mosquito's potential devastating impacts exists from other important outbreaks of chikungunya virus on La Reunion island in 2005–2006, with more than 250 000 infections and several deaths. Indeed, the outbreak on the Indian Ocean islands involved hundreds of thousands of people, including travellers from industrialised countries with temperate climates, who were still positive for the virus upon returning to their native countries. Parasites affecting other animals have also been isolated, for example the dog heartworm in Italy. Of course, in addition to the health impact, the invasion of this mosquito has also a major economic impact, particularly in relation to health nuisance and treatment costs for both prevention strategies and implementation of related management activities.

Map of Asian tiger mosquito (*Aedes albopictus*)



Source: Based on Roques, 2008.

Aside from its role as vector of diseases, the Asian tiger mosquito is also known as an aggressive diurnal biter — unlike most other mosquitoes which are crepuscular or nocturnal — and as such represents a serious nuisance, particularly in the summer periods when it reaches high densities.

The Asian tiger mosquito also seems to have a competitive advantage over a number of other mosquito species; therefore, some experts argue that its spread may actually result in a net gain for public health. For example, in many places it is displacing the so-called yellow fever mosquito *Aedes aegypti* — a species native to Africa now found in all tropical and subtropical regions of the world, which feeds almost exclusively on humans and is an even more important vector of some diseases than tiger mosquito, notably dengue virus.

Distribution and pathways

The tiger mosquito is native to South-East Asia, including the islands of the Western Pacific Ocean and Indian Ocean. It has been introduced since the 19th century in about 40 countries in Africa, the Caribbean, the Middle East, western and southern Europe, and North and South America, and has become established in most of them. In western and southern Europe it spread very rapidly over the past two decades. Established populations are present in Albania, Bosnia and Herzegovina, Croatia, France, including Corsica, Greece, Monaco, Montenegro, the Netherlands (indoor), Italy, including Sicily and Sardinia, Slovenia, Spain and Switzerland, plus — but needing further confirmation — Belgium and Germany. Italy is by far the most heavily infested country in Europe. Predictions under different climate change scenarios show that the species will likely expand its European range even further in the near future, particularly in the Mediterranean basin, but also as far north as the Baltic states and part of Scandinavia. Since the flight range of adults is limited to a few hundred metres, any long-distance dispersal needs to be mediated by human activity. The main pathway, particularly for eggs and larvae, has been the intercontinental trade in used tyres. For example, the source of tiger mosquito infestation in Italy in the 1990s was identified as a warehouse of a tyre rethreading company that had imported used scrap tires from the United States infested with mosquito eggs (due to the rainwater retained in the tires when stored outside). Passive transport by aircraft, boats and terrestrial vehicles of dormant eggs or larvae in moist vegetation or other water containers also contributed. A pathway of increasing importance is the trade in plants known as 'lucky bamboo'. Repetitive introductions of tiger mosquitoes in Dutch greenhouses in which the lucky bamboo plants that originate from southern China are maturing have been observed since 2005.

Management

The introduction of sterilisation or quarantine measures is pivotal to control the spread of the tiger mosquito through trade. Removal of discarded tires represents the soundest management technique; whenever possible, all sources of standing water (any container that can hold rainwater) should be removed or emptied regularly in areas at risk. Other water reserves that cannot be dumped can be treated with a spoonful of vegetable oil to suffocate mosquito larvae. However, larval or adult control within tyre dumps have proven to be difficult and relatively inefficient due to the shape and abundance of the water surfaces. Water sprayed with derivates of *Bacillus thuringiensis israelensis* or diflubenzuron (a larval growth inhibitor) can be used to control the larval stages. In addition, planktonic predators (like copepods) may be used for container-breeding larvae, and fish and dragonfly larvae in other situations. To control adults, spraying with pyrethroids is practiced. In addition, traps using ammonia, fatty acids, lactic acid and particularly carbon dioxide to produce a smell similar to that of a human body in an upward air current can be effective in collecting these mosquitoes. Other control techniques include the use of oviposition traps, as well as artificial breeding containers (e.g. tyres) baited with carbon dioxide (CO_2) from dry ice.

Impacts of IAS on human health — disease vectors

Raccoon dog *Nyctereutes procyonoides*

The raccoon dog

Species description

The raccoon dog is an omnivorous carnivore the size of a fox, characterised by a relatively elongated body, short legs and tail, and a small head with short rounded ears. Body colouration varies from yellow to grey or reddish. Other typical features include a black facial mask and long hair on cheeks. Its invasion success has been facilitated by a great plasticity in adaptation to various climatic and environmental conditions. Raccoon dogs live preferably near water in forest habitats with abundant undergrowth like river valleys, lakeshores, and marshes, but depending on food availability, also on agricultural area intersperse with woodlands. The ability to hibernate in winter and high reproductive capacity are other typical features of this successful invader. In fact, raccoon dogs achieve sexual maturity at 9–11 months and most juveniles disperse at 4–5 months of age. The litter size in Europe is higher than in the native range (up to 16, but about 8 on average). Average dispersal distance does not exceed 20 km, but animals are known to move even 400 km in low productive habitat in their northern expansion area.

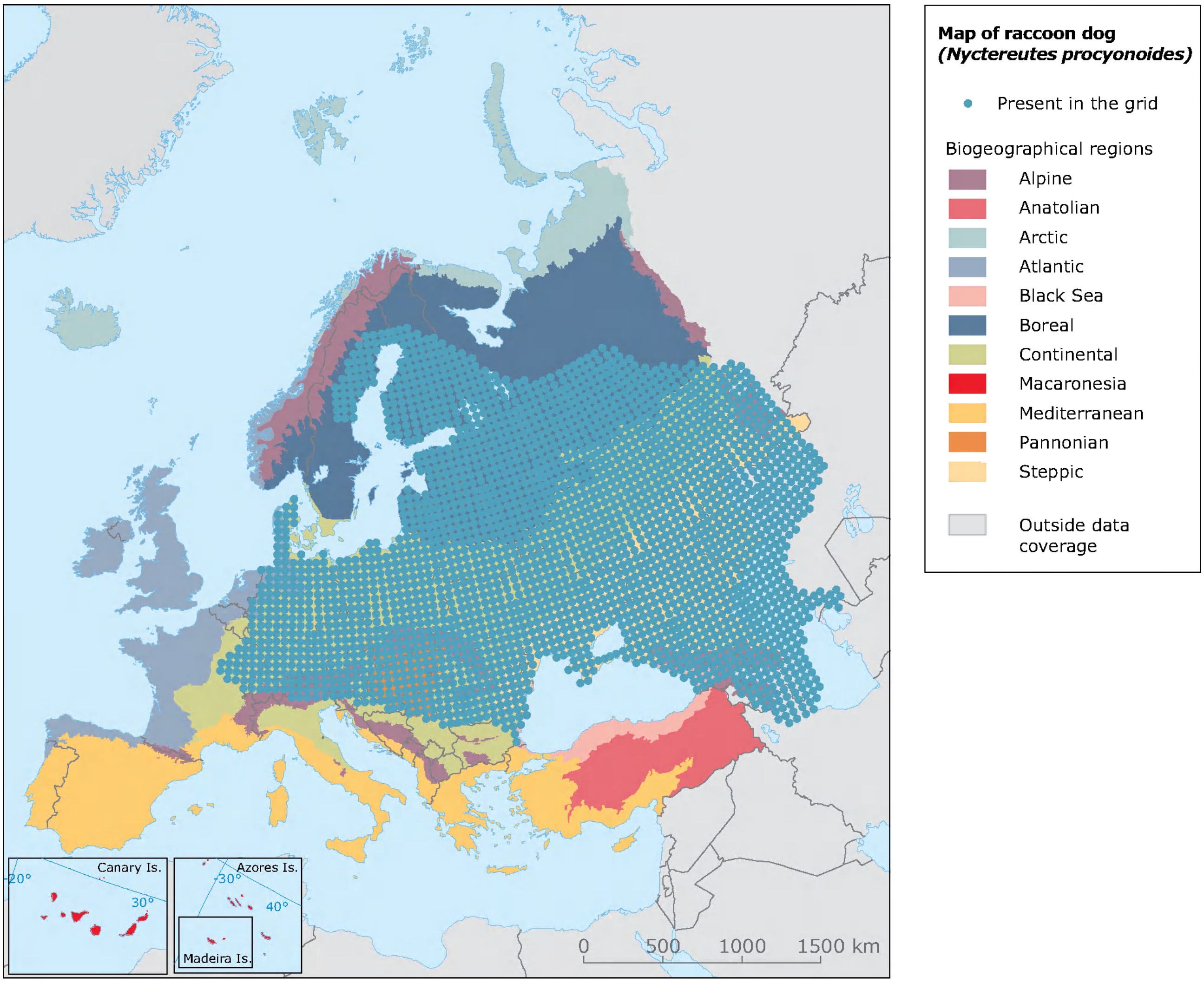
Impacts

The raccoon dog is a vector of many important diseases and parasites. First of all it is one of the main terrestrial rabies vectors in Europe. The significance of this species as a vector of rabies has recently increased and, in situations of high density, raccoon dogs can be even a more common vector than the red fox (which has been the main terrestrial wildlife rabies vector in Europe since the Second World War). Cases of rabies occurring in raccoon dogs were observed in Belarus, Estonia, Latvia, Lithuania, Poland, Russia and the Ukraine. For example, during sylvatic rabies epizootic in Finland in the late 1980s, 73 % of the observed rabies cases were in raccoon dogs. In Poland over 700 raccoon dogs (i.e. 8 % of all cases) with rabies were recorded in the period 1999–2004. In Lithuania the prevalence of rabies in raccoon dogs increased sharply in

10 years (almost 2.5 times from 11.8 % in 1994 to 28.9 % in 2004). In Estonia, over 50 % of wildlife rabies cases were found in raccoon dogs in 2004. The role of the raccoon dog as a vector of rabies may further increase in Europe, because the raccoon dog population is still growing and spreading, and a high risk of distribution of this disease comes by dispersing juveniles. Scavenging on other mammals may also facilitate the spread of the disease, which is transmitted in direct contact.

This species is also an important reservoir and vector of other dangerous parasites that infect humans, such as the sarcoptic mange, the trichinella worms and fox tapeworm. In particular, while the first two can have a higher prevalence and risk of infection in wild animals, the latter represents an increasing public health concern. In fact, the spread of the fox tapeworm in Europe (where new endemic areas have been detected in recent years) has been associated with the growing fox and raccoon dog populations. Although in Central Europe the definitive host of this parasite that can cause lethal diseases in humans has been the red fox, many new cases have been recently detected in raccoon dogs too. Therefore, the raccoon dog may provide an additional pool of definitive hosts in Europe, and given the high densities of the species in some areas, it can be a serious source of infection. For example, while the prevalence in foxes in areas of zoonosis is 35–65 %, prevalence in raccoon dogs was 8 % in Poland and up to 12 % in Germany. The parasite has even invaded cities, and is now found in

Map of raccoon dog (*Nyctereutes procyonoides*)



Source: Based on Kauhala and Kowalczyk, 2011.

Austria, Belgium, the Czech Republic, Denmark, Estonia, France, Germany, Italy, Latvia, Lithuania, the Netherlands, Poland, Slovakia, Slovenia, Sweden and Switzerland (so far it is absent in Finland).

In addition to causing health problems to humans, its role as a vector of diseases and parasites such as rabies, scabies and fox tapeworm is also likely to cause considerable ecological and economic impacts. Other viruses dangerous to humans have been found in raccoon dogs in China, including SARS (Severe Acute Respiratory Syndrome) and avian H5N1 viruses, also known as 'bird flu'.

Raccoon dogs have additionally fallen victim to canine distemper virus (CDV) in Japan. CDV may have the most far-reaching consequences of all infectious agents for free-living carnivores. Moreover, transmission of CDV between wild carnivores and the domestic dog is also possible.

Raccoon dogs may also have some major impact on wildlife. They are opportunistic omnivores with a much wider diet than those of most other carnivores. The predatory impact may differ from area to area, depending on availability of food resources and the local fauna composition. For this reason it may become a threat to waterfowl and other bird species, particularly on islands, as well as amphibians. Such a threat could result in decreased nesting success of the affected species and/or decreased population sizes. There may also be competition for food and den sites with other carnivores, such as the badger or the red fox.

Distribution and pathways

The native range of the raccoon dog covers large parts of China, north-east Indochina, Japan, Korea, Mongolia and eastern Siberia (Amur and Ussuri regions). Further to the introduction as fur game species of about 9 100 individuals in the European parts of the former Soviet Union, between 1929 and 1955, the species is now widespread in northern and eastern Europe mainly as a result of secondary expansion (but in some regions animals also escaped from fur farms). It is widespread and common in Belarus, Estonia, Finland, Germany, Latvia, Lithuania, Poland, western Russia and the Ukraine. It is also present in Bulgaria, the Czech Republic, Denmark, Hungary, Moldova, Romania, Serbia, Slovakia and Sweden. It is sporadically seen in Austria, Bosnia and Herzegovina, France, Italy, the Netherlands, Norway, Slovenia, Spain and Switzerland. It is expected that the raccoon dog will expand its range in the already invaded countries very quickly.

Management

Given the role of the raccoon dog as a vector of diseases and parasites, and its impact on native fauna, it should be controlled in every country. Although there is probably no possibility of eradicating the raccoon dog from the wild, intensive trapping with box and wire traps and hunting with dogs may be effective methods to control raccoon dog populations locally (although like other canids, they tend to increase their litter size when hunting pressure on them is high). Moreover, some attempt is being made to completely prevent the expansion of raccoon dogs in Europe. For example, a EUR 5.3 million LIFE project, 'Management of the invasive Raccoon Dog (*Nyctereutes procyonoides*) in the north-European countries', has been financed for the period 2010–2013 to prevent the raccoon dog from establishing in the Nordic countries, and — where it has already invaded (parts of Finland) — to keep the population reasonably confined and try to stop its further expansion into other countries. An innovative method has been effectively developed and applied in the project, based on the use of Judas animals. The method consists of releasing some radio-tagged raccoon dogs that due to their social nature will search for other raccoon dogs of the opposite sex in the area, thus allowing for their capture/culling.

Impacts of IAS on human health — health impacts

Common ragweed *Ambrosia artemisiifolia*

The common ragweed

© Photo courtesy of Daniela Bouvet

Species description

The common ragweed is an annual herbaceous plant which can reach a height of over 2 m, usually with many branches. The leaves are bright green on both sides with whitish nerves and are 4–10 cm long. Both the flowers and the fruits are very small (up to 4 mm). The common ragweed produces large quantities of pollen, usually in August to September. The common ragweed is a pioneer species with great adaptability to hostile habitats (in absence of interspecific competition). It is most frequently associated with agriculture and is found in cultivated fields (mainly maize, sunflower, leguminous plants) and along irrigation canals. It is also associated with frequent and extensive disturbance regimes resulting from other human activities. Examples are riverbanks and temporary watercourses, roadsides and railways, gravel pits, construction sites, ruderal sites and waste sites, urban areas, building yards, private gardens and parks. Plants grows best on nutrient-rich bare mineral soils (sandy and pebbly) or sparse vegetation and adapt to a wide range of pH. In general they are resistant to high summer temperatures, drought and moderate soil salinity, and have strong ability for re-growth after mowing. The seeds may remain viable for at least 40 years in soil seed banks.

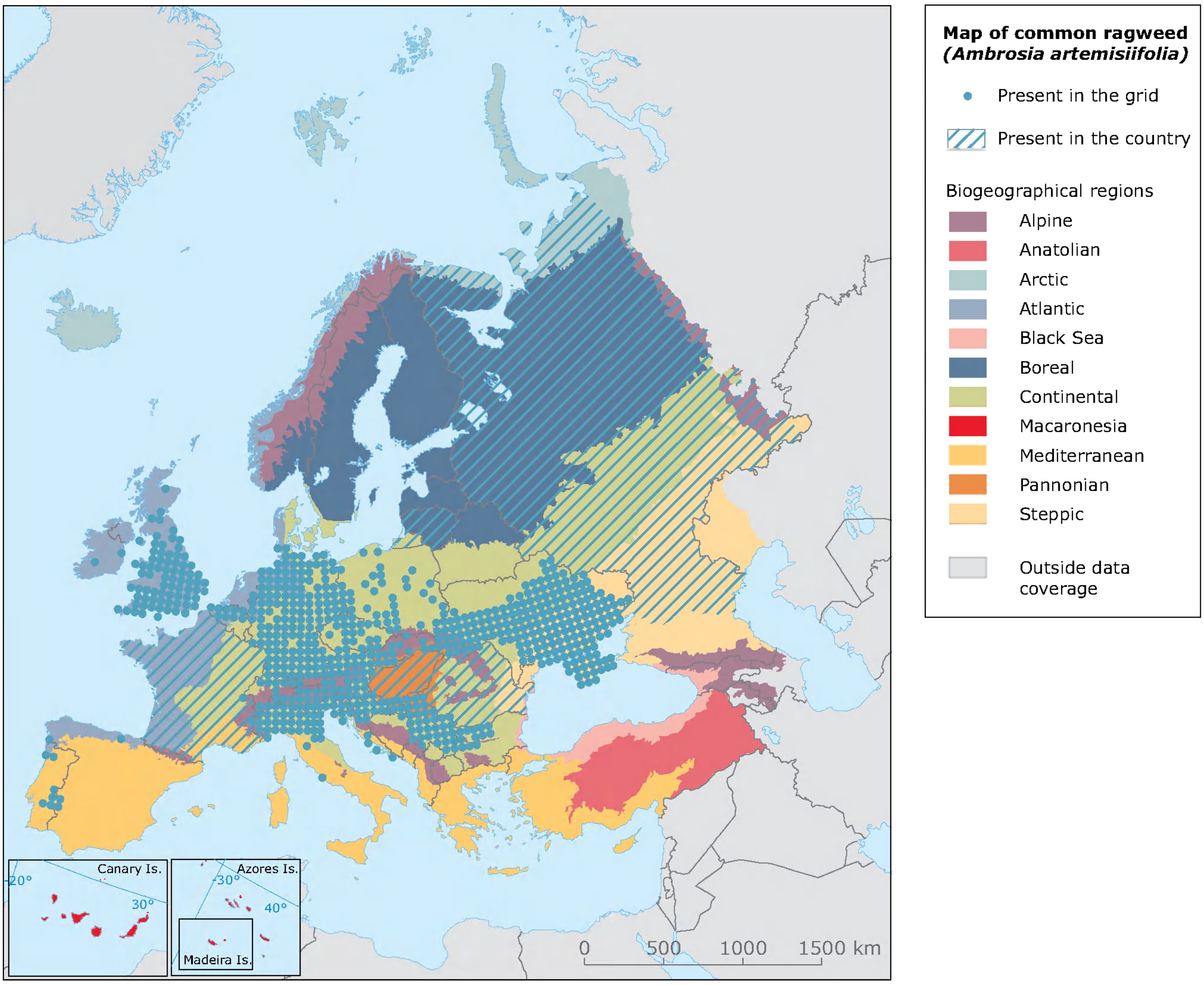
Impacts

The common ragweed is one of the most pollen-allergenic plants and as such represents a serious health risk for humans. Its pollen is a potent trigger of hay fever, rhinoconjunctivitis, and may often cause severe asthma-like symptoms. In some European countries where large ragweed populations are present, 10–20 % of patients with pollen allergy symptoms suffer from ragweed allergy. The impact of common ragweed on human health is not restricted to areas invaded by the plant. In fact, due to wind-borne spreading of the very large production of light pollen, allergy reactions are recorded in distances over 200 km from the site where the plant is situated. Moreover, there is evidence for large-scale (80 %) cross-reactivity between the allergens of other species of ragweed, among which is the mugwort. This implies a high risk of developing multi-hypersensitivity, which in turn might cause affected persons to have a prolonged period of exposure to allergens. In addition, the common ragweed also contains volatile oils that may cause skin irritation and hypersensitivity dermatitis, typically with symptoms of dermal congestion, hyperaemia, development of serous vesicles and itching. The associated economic costs are estimated in several hundreds of millions of euros. In Italy, for example, the costs of human ragweed allergy have been calculated to amount to almost EUR 2 million per year in the Milan province only. In Europe, the common ragweed constitutes a growing problem also as an agricultural and non-agricultural weed. Because of the strong development of both aerial and underground parts, this weed is a serious noxious plant of various crops, for it may cause quick drying (it takes up two times more water than cultivated plants) and may impoverish the soil, which may result in high economic losses for plant production. Moreover, some plant extracts seem to have significant inhibitory effects on the germination of crops such as pea, bean, corn and sunflower. The common ragweed might also have a major impact on farming activities. This weed is not palatable to livestock and its presence may greatly reduce the fodder quality of meadows and pastures. It may even taint dairy products if cattle do feed on it. Moreover, because of erect, hard stems, the ragweed plants make the harvest of cereals and other plants with agricultural machines difficult. Finally, dense infestations of this weed can also affect the biodiversity of vegetation. For example, in the Ukraine steppe zone, the common ragweed inhibits progressive succession by suppressing both annual and perennial plants, and thus decreasing species diversity in the ecosystem.

Distribution and pathways

Common ragweed is a native to North America (Canada and USA) from where it has been introduced mainly as a contaminant of agricultural products, machinery or construction materials into the temperate zones of Europe and in parts of Australia, China, Japan, South America and Taiwan. Although the presence of common ragweed in Europe was recorded in France as well as in Germany already in the 1860s, its spread in the entire region started only 20 to 25 years ago. Large

Map of common ragweed (*Ambrosia artemisiifolia*)



Source: Based on Winter and Pergl, 2008d.

populations of ragweed are currently present in Croatia, France, Hungary and Italy, but the distribution range is already expanding northward as a consequence of changing climate and perhaps adaptation to local climate in Europe. Because the most important pathway in Europe is agricultural products contaminated with common ragweed seeds imported from North America (including the grain mixtures used as food for birds), worldwide and intra-Community trade increases the risk of ragweed spreading. Moreover, changes in agricultural land use with large-scale set-aside and abandonment practices, along with an increase of the construction sites and wasteland, are expected to provide new suitable habitats for ragweed.

Management

Common ragweed is now so widespread in Europe that eradication at this stage of the invasion is no longer feasible. The consequences for public health and costs are very important. However, two important management options are still feasible: (a) to keep ambrosia under control where it has already infested the seed bank, by every year eliminating seed production and pollen of emerging plants as far as possible, and (b) preventing or reducing the spread of seeds from infested to non-infested sites. Preventive measures should include initiatives to limit unintentional spread of ragweed seeds by developing and implementing best practices. Awareness-raising activities focusing on the impact of common ragweed on human health as a cause of hay fever and asthma and as a potential pest weed would help the general public to become familiar with the plant and to help prevent its spread by, for example, reporting observations making early detection possible. Implementation of control measures vary from country to country and mostly depend on relevant framework legislation at both the national and local levels. The most effective management measures to control the propagation of this plant include clipping/mowing (one to three sessions per year are required, according to the different habitats and situations), uprooting, ploughing, mulching and chemical treatment. According to the experience in Italy, mowing is the easiest method for many types of land. It is usually very effective (success rate 97 %) because it guarantees reduction of both plants and flowers on plants. Chemical treatment is another easy method for many types of soil. Also, this method is very effective (success rate 97 %), but special attention must be paid to the period of interventions and the equipment used, including the active ingredient. Glyphosate is an example of an active ingredient with low environmental impact if used properly. Mulching is a method preferably applied in urban environments, with good results (100 % success), small environmental impact and very useful for small areas. Uprooting is another method preferably applied in urban environments, which allows total eradication of the plant, particularly suggested in sites newly invaded and wherever there are only small populations. Ploughing is a method applied in agricultural habitats, which is less effective (90–95 % success rate if applied to soil with an optimal level of humidity and plants not taller than 20 cm) because it requires a very accurate identification of the methodologies and the timing of the interventions. So far, no successful biological control methods have been developed.

Impacts of IAS on human health — health impacts

Giant hogweed *Heracleum mantegazzianum*

The giant hogweed

Species description

Giant hogweed is a large plant that can grow up to 4 m in height with leaves up to 2.5 m in length. It lives 3 to 5 years as a rosette and usually flowers only once per lifetime (monocarpic) and dies after seed production. A single plant can produce up to 20 000 seeds or more, but seeds are rather short-lived and do not stay fertile in the soil seed-bank for longer than a few years. Giant hogweed invasion usually starts as cultivated in the vicinity of man-made habitats then spreads along road, railway and water corridors to abandoned meadows and grassland, forest clearings, forest and field edges. Colonisation can start from single plants and can lead to dense, monodominant stands. Because of its combination of traits that support invasion, it is called a 'master-of-all-traits' of plant invasions.

Two similar hogweed species were introduced as ornamental plants to Europe in the 19th century, the Persian hogweed and the Sosnowsky hogweed, which currently are less frequent, but can create the same impact as giant hogweed.

Impacts

The major impact of giant hogweed is on human health. Photosensitive metabolites (furanocumarins) on human skin react under ultraviolet (UV) radiation (sunlight) with a burning sensation reaction that can cause serious skin lesions. Sensitive people may even react to physical contact with any part of the plant, whereas some people do not react at all. However, toxicity is of major concern during all management actions taken against this plant. Economic costs of eradication and medical treatments were estimated for Germany to be in the range of EUR 6 to 21 million per year. The density of populations varies considerably from sparse growth (one to three plants per 10 m^2) to dominant stands (more than 20 plants per 10 m^2). Negative impacts on local biodiversity are known, as dense monodominant stands reduce composition and diversity of native plant species up to 90 % compared to uninvaded sites. The large height and leaf area specifically suppress light-demanding native plant species. Because of its habitat preferences abandoned grasslands and ruderal habitats are particularly affected. This also reveals negative impact on cultural services, because monodominant stands cause changes in the recreational value and accessibility of invaded areas. When the large inflorescences flower, they are visited by many insects, such as wildbees, wasps, flies and beetles, who serve as pollinators, but selfing is also possible. No comprehensive analyses are available on the effects on pollinators and herbivores.

Positive effects of giant hogweed include its decorative value, usage by beekeepers and hunters, and as fodder crop. It should be said clearly that for all these motives other native species are equally qualified and there is no well justified reason to intentionally plant giant hogweed in Europe.

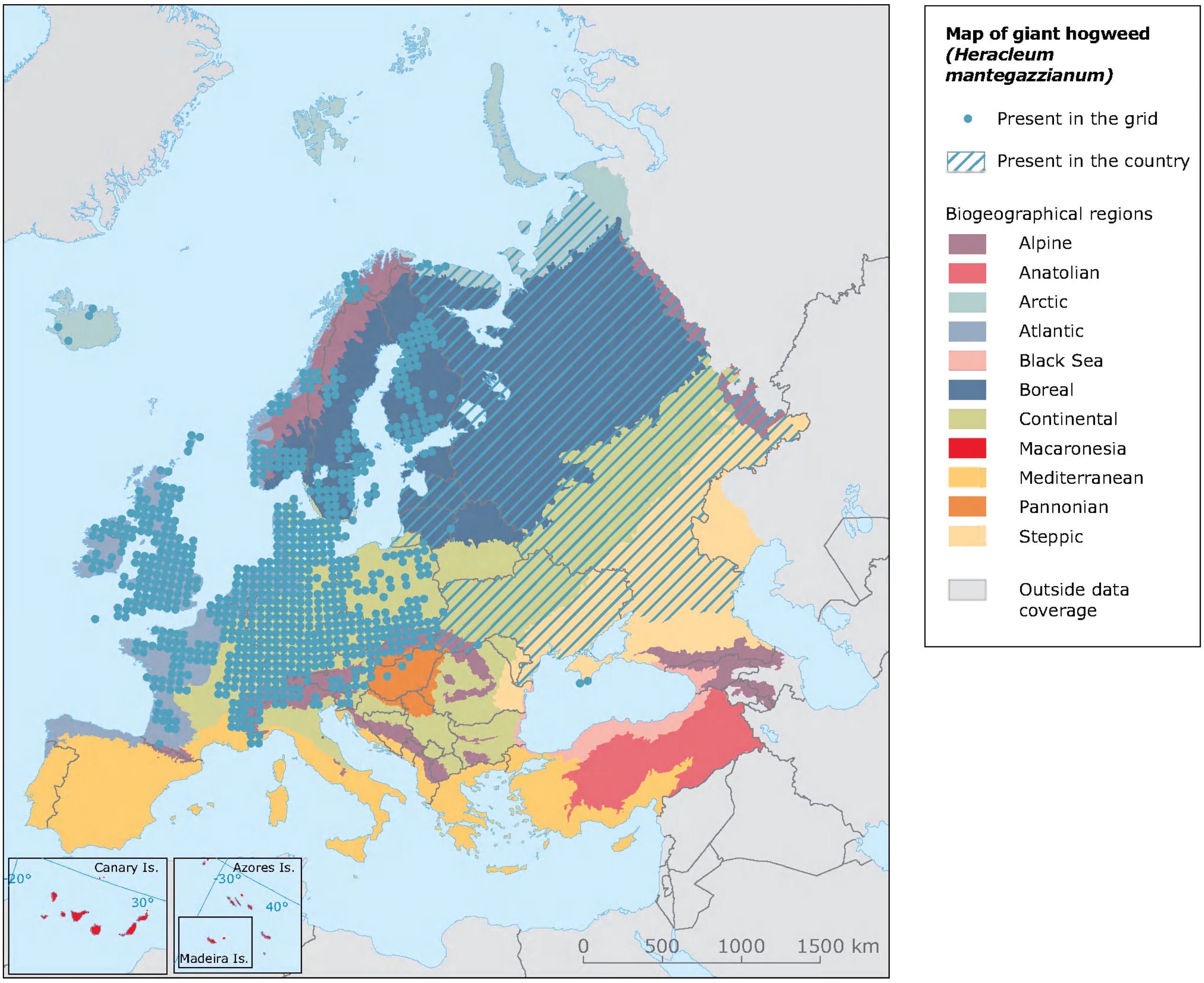
Distribution and pathways

Giant hogweed is native to the western part of the Caucasus, where it lives in subalpine tall herb communities on wet and nutrient-rich soils in low densities. It was introduced to Europe as an ornamental plant in 1817 in Kew Botanic Garden (London) from where it soon escaped. Then it was intentionally planted across Central Europe for ornamental purposes, as bee pasture by beekeepers and as fodder crop. Today it is distributed over large parts of central and east Europe, but is still absent from south Europe, where the dry and warm Mediterranean climate limits its establishment. In some regions in eastern Europe it was used as silage fodder, but it soon turned out to be inappropriate and unprofitable, leaving large abandoned fields from where the species spread. Natural dispersal capacity by wind and water of seeds, however, is comparatively low. The species is still intentionally planted occasionally and genetic analyses confirm repeated independent introductions.

Management

Different control techniques are available; however, utmost care (e.g. using protective clothing) has to be taken during any manipulation with all parts of this plant. In addition, the appropriate timing of measures regarding plant life history is crucial. Mechanical control by repeated grazing and cutting should be executed during flowering and before seed-setting. Very effective but laborious is the cutting of roots at 10 cm depth. Chemical control with herbicides is possible, but costs and side-effects need to be considered. Despite intensive research, no efficient biological control pathogen or insect is currently available. Due to the regenerative capacity of the species, management needs to be continued over several years, accompanied by a compulsory post-management monitoring.

Map of giant hogweed (*Heracleum mantegazzianum*)



Source: Based on Pergl, 2011; and Nentwig, 2011.

Impacts of IAS on economic activities — damaging infrastructure

Coypu *Myocastor coypus*

The coypu

Species description

The coypu is a large rodent, with a brown fur, short legs and a long cylindrical tail. The weight of this large semi-aquatic mammal is between 2–4 kg, although adult males can reach 7–8 kg. Coypus are good swimmers (they are characterised by webbed digits of the hind feet) and can adapt to a wide variety of aquatic habitats, from freshwaters, rivers, marshes and lakes to drainage canals (it is rarely observed more than 100 m away from water bodies). They usually live in lowlands, but can live in areas up to 1 200 m altitude in the Andes, and are herbivorous except for occasional feeding on mussels. Coypus can breed throughout the year. The age of first parturition in this rat-like species is 3–8 months, and the mean litter size at birth is 4–5 (e.g. in England or Italy). In good habitats females may give birth two to three times per year with an average of 15 offspring/year. Cold winter reduces breeding success and influences the population dynamics.

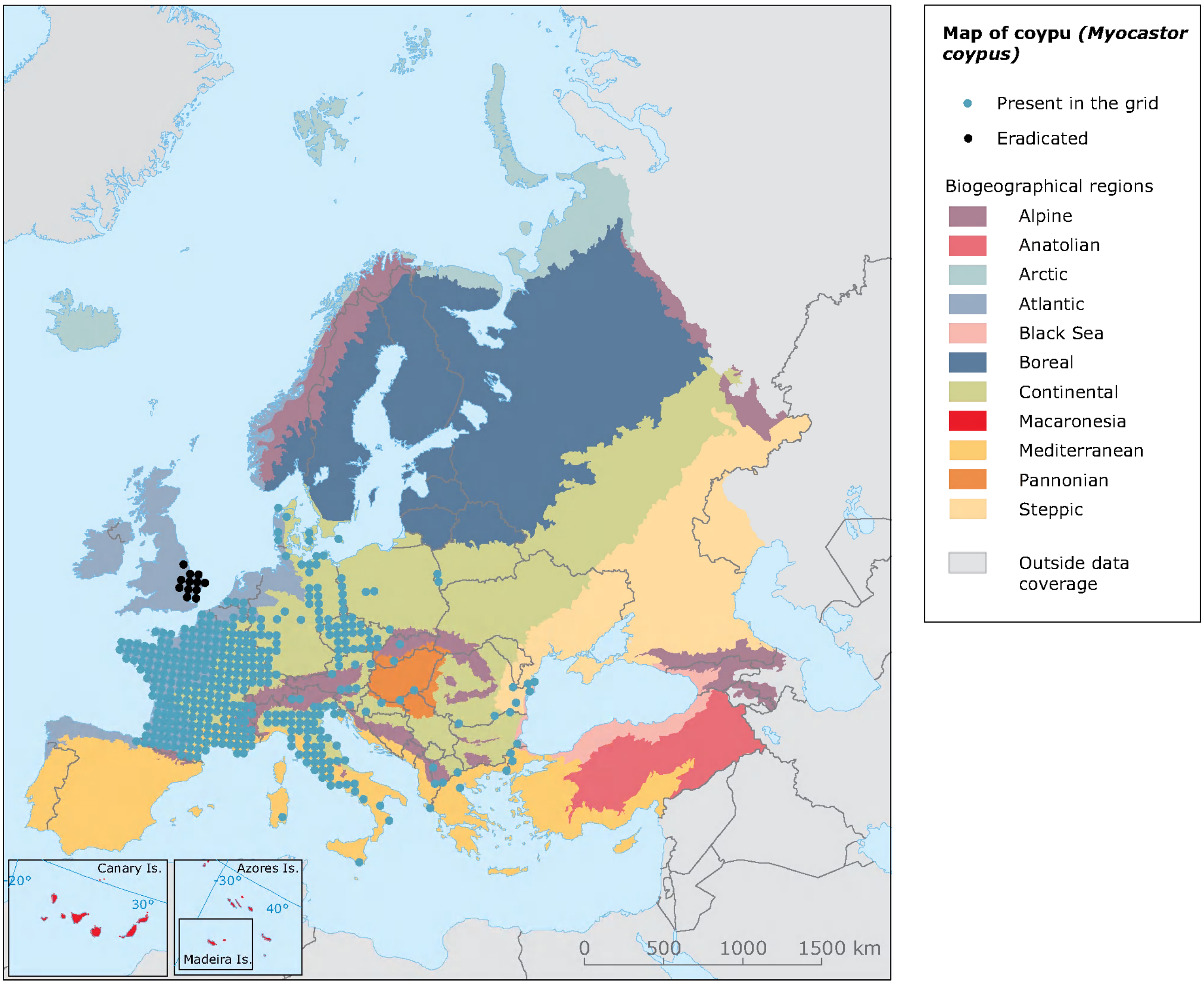
Impacts

The coypu is considered as a major threat for a number of reasons, including the important economic damages caused by its burrowing behaviour. The coypu's extensive burrowing activity can undermine human infrastructures such as riverbanks and dykes, which in turn can disrupt drainage systems and pose a risk of flooding in low-lying areas. For example, in Italy the impact during 1995–2000, despite control activities involving the removal of 220 688 coypus at a cost of EUR 2 614 408, damage to the riverbanks exceeded EUR 10 million (plus EUR 935 138 for the impacts on agriculture). The coypu's burrowing activities on dykes and levees make them more susceptible to collapse not only in relation to flooding, but also other factors such as road and rail traffic. In North America, the functionality of artificial wetlands constructed for sewage treatment may be impaired by the growth of coypu populations which can dig extensive burrow systems across them.

The species is considered to be one of the worst invasive species also because of the damage they cause to agriculture, and also the potential damage they cause in urban wetlands such as golf courses. Coypus are moreover considered as a pest for their foraging on crop plants, such as sugar beets and maize, but also cereals, sugarcane, alfalfa, brassica, ryegrass, fruit and nut trees. However, coypus prefer not to feed on exposed land far from water; the impacts of this pest is clearly dependent on the specific habitat characteristics and the type of management of riverbanks and irrigation canals, which affect food availability and proximity to water. In general they behave as an agricultural pest — and as such may especially impact crops cultivated next to the water — especially if the natural vegetation they prefer is scarce. Thus, damages are limited in European countries where agricultural land and farmland do not have a fringe of natural and semi-natural vegetation close to the banks with food resources suitable for coypus.

The coypu is also a typical example of an IAS causing impacts on biodiversity and human health. Besides feeding on aquatic vegetation it could impact several aquatic birds by destroying their nests used as resting platforms. Selective feeding by coypus caused massive reductions in reedswamp areas and eliminated native plants over large areas. Moreover, it has been hypothesised that the species has a role in the epidemiology of leptospirosis, although its role is probably less important for the spread of the bacteria in the environment compared to rats.

Map of coypu (*Myocastor coypus*)



Source: Based on Genovesi and Scalera, 2008b.

Distribution and pathways

The coypu is native to the Patagonian subregion of South America and is present in the northern part of Argentina, Bolivia, southern Brazil, Chile Paraguay and Uruguay. In the early part of the 20th century it was introduced into several regions of the world such as East Africa, Europe, Japan, the Middle East and North America. The rodent repeatedly escaped from the fur farms and/or was intentionally released into the wild with the aim of being harvested for its fur. In addition, coypus are fast colonisers, able to occupy rapidly vacant suitable habitats using freshwater as a pathway. In Europe the coypu is now widespread in several countries, for example Belgium, the Czech Republic, Germany, France, Italy (including two small populations in Sicily and Sardinia) and the Netherlands. Ranges and population densities are increasing in many countries where the species is still spreading. For example, in Spain coypus are entering from France. On the other hand, in the United Kingdom (East Anglia) the species is no longer present thanks to a successful eradication campaign that lasted 11 years.

Management

In America and Europe there are many permanent population control programmes to reduce densities and spreading of the species. Coypu is usually controlled with the use of cage-trapping and shooting. Shooting is effective when environmental conditions force the animals into the open, while cage-trapping has been used also in eradication programmes. In France and the United States, baits with toxicants are also used. To protect farming activities and crops, and to avoid damages to infrastructures (i.e. on riverbanks and dykes) by burrowing animals, buried or partially buried fences have been used with some success.

The eradication campaign carried out in England is certainly one of the most successful examples of a definitive removal of an exotic mammal on a larger island. Key aspects leading to such a successful campaign, to be used as a reference for future actions, were accurate technical planning, careful evaluation of the human dimension, and continuous financial and logistic support over the project period.

Although the high costs associated with eradication campaigns may discourage authorities from undertaking such initiatives, it should be considered that permanent control to limit damage can be even more expensive. For example, it was calculated that in Italy, where coypus cannot be eradicated any longer (the population is too widespread and well established), the costs of permanent control campaigns carried out locally over only six years were EUR 14 million, against only EUR 5 million (cost updated to year 2000) spent over 11 years for total eradication of the species in the United Kingdom. According to future scenarios, the Italian coypu range may expand 2.5–3.3 times, and economic losses may reach EUR 9–12 million/year. In fact, the control campaigns are not stopping the population expansion or the increase in damage and economic losses at a national scale. Considering that in many areas the population density is far from saturation, the cost of management may increase far beyond our predictions. This shows that even very costly eradications, if successful, may have a very positive cost-benefit ratio in the long term.

Impacts of IAS on economic activities — damaging infrastructure

Zebra mussel *Dreissena polymorpha*

The zebra mussel from Chepintsi Lake near Sofia

Species description

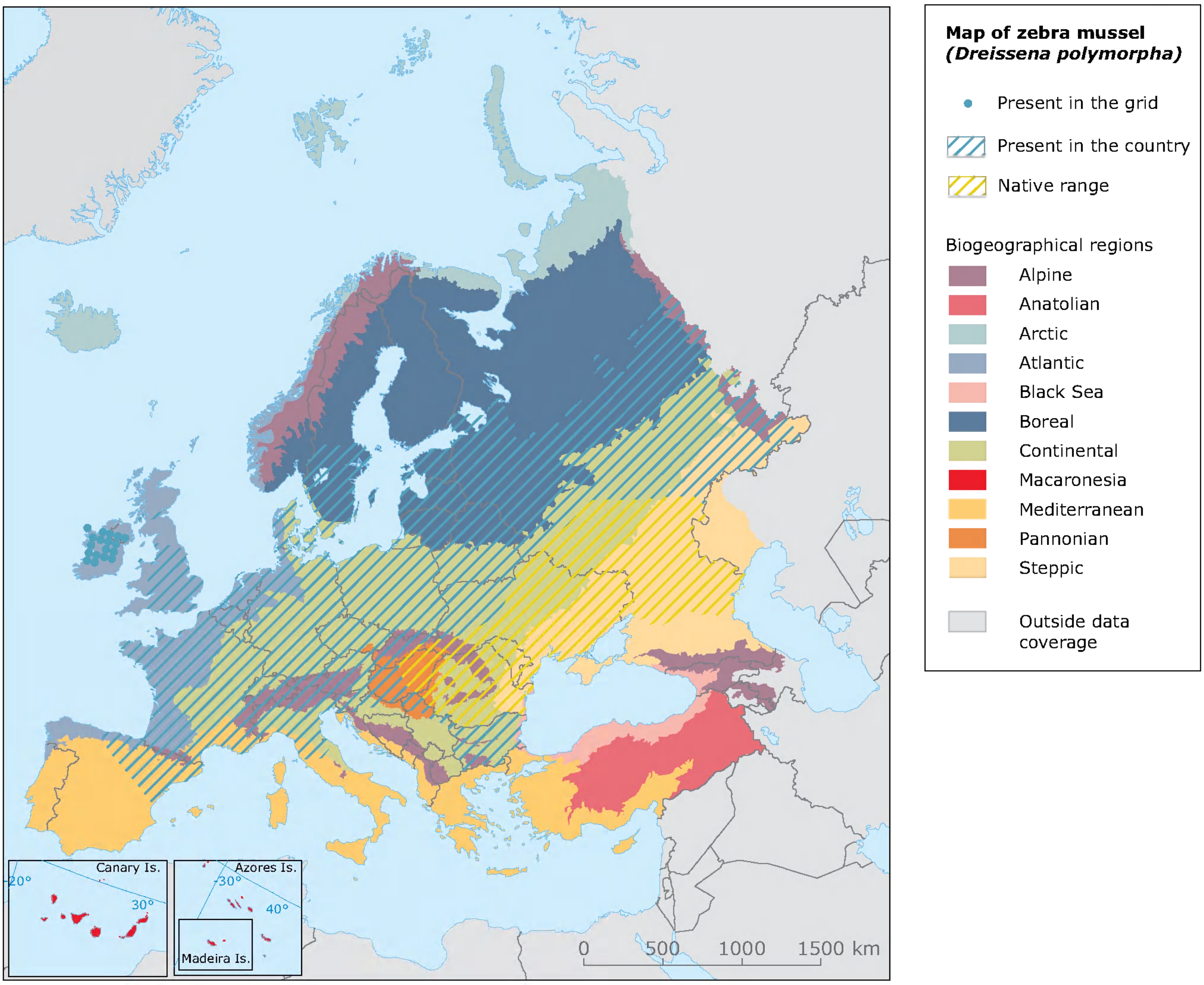
The zebra mussel is a bivalve mollusc with a strong, thick and keeled triangular shell with a prominent dark and light zigzag banding pattern, hence its name. This small filter-feeding organism, whose length is up to 5 cm, forms dense colonies on various hard substrates suitable for attachment (particularly rocky surfaces) in fresh and slightly brackish waters. The typical habitats colonised by the species are estuaries, rivers, lakes and other inland waters (e.g. the calm waters upstream of dams), where it occurs from the lower shore up to depths of 60 m in lakes. It inhabits a range of clean and well oxygenated freshwaters, but is able to live also in waters with low oxygen for several days (and can survive out of water for a few weeks under cool damp conditions). Moreover, it can tolerate temperatures from – 2 °C to 40 °C , although it grows best at 18–20 °C. These molluscs have a great reproductive capacity, since a mature female may produce one million eggs per year. It feeds on microscopic plankton organisms and organic particles, and is preyed upon by many different fish (e.g. roach, carp, eel) and other predators, such as diving ducks, crayfish and muskrats.

Impacts

The negative economic impacts associated with the zebra mussel arise from the dense clusters formed by this species on the hard substrates where they attach by secreting sticky threads known as byssus. Typical substrates include masonry, stones, wooden posts, tree roots, deadwood, walls of embankments, hulls of ships, and buoys, but it may also attach to other bivalves (including those of their own species as they can even grow onto each other), crustaceans and snails. These clusters produces dense encrustations which are responsible for fouling of intake pipes, ship hulls, navigational constructions, cages of aquaculture and reduces angling catches. In this way the zebra mussel can provoke a number of damages, for example by causing the clogging of the water-intake/supply of industrial and drinking water plants, affecting lock gates and other hard structures in the water, and blocking pipes, vents and any holes or openings where water flows. On the other hand, even when pipes and tubing are not completely blocked, they can lose capacity due to section loss and increased friction. Furthermore, when the mussels die, the decay of the filaments of the byssus may accelerate corrosion of joints in metal structures due to the proliferation of bacteria producing an acid component through aerobic respiration affecting iron and steel surfaces. This problem has had a major impact on a number of infrastructures such as irrigation systems, drinking water supplies, hydroelectric and nuclear plants, recreational areas and private properties.

Major economic losses and additional costs of maintenance are thus connected to problems in the operation of affected facilities (pipeline obstructions, interruptions) that have to stop production to be mechanically cleaned. In addition, recreational boats, jetties, floats, fishing nets and in general any equipment in contact with the water (e.g. engines of recreational crafts) may also be affected resulting in additional maintenance costs. In terms of impact on recreational use, there are also some effects on human health. Injuries to bathers, resulting from stepping on the sharp edges of the shells, have been documented. In fact, when shells are massively spreading across the shore, it is practically impossible to walk (and this also results in very

Map of zebra mussel (*Dreissena polymorpha*)



Source: Based on Olenin, 2008.

high costs of cleaning). As an example, an economic study carried out in Spain in 2005 predicted a cost of around EUR 40 million over 20 years.

There are also reports of positive effects by the infestation of zebra mussels. For instance, it is an important food component for some fish, crayfish and birds. Shells can be used as fertilisers and poultry food once crushed. Another claimed benefit is the increase of water clarity documented in many lakes after the arrival of this alien bivalve, which may counteract the negative effect of eutrophication and pollution from human activities. However, it is also known that in response to an increase in water clarity the food-web dynamics of entire ecosystems may be compromised, for example the phytoplankton component may fall dramatically, leading to a population decline of some fish, an increase of submerged vegetation, and an alteration of the overall cycle of nutrients. Moreover, some 'undesirable' positive synergy with other IAS, such as the killer shrimp, has been highlighted. Finally, the zebra mussels may also out-compete native mussels and other filter-feeding organisms. In Spain, for example, in the Ebro River the arrival of the zebra mussel threatens the survival of the world's largest population of the endangered native Spengler's freshwater mussel.

Distribution and pathways

The zebra mussel, a native to the drainage basins of the Aral, Black and Caspian Seas, was introduced from eastern to western Europe during the 19th century through a corridor of river basins interconnected by the opening of new man-made waterways. This species is present in central and western Europe, Great Britain, Ireland and southern Scandinavia, and further range expansion is expected in the near future (the species is already extending east into western Asia and south into Turkey). The zebra mussel was introduced also to North America.

The most effective introduction vector is shipping, for example through ballast water or as fouling on ship and recreational boat hulls, navigation buoys, fishing vessel walls. However, other pathways are known. It could be transported with timber or river gravel, and overland transport, for example as a contaminant of fish stocking water and fishing equipment, as well as with other animals (including crayfish) transported for stocking in farms.

Management

In order to minimise the risk of spread by transfer of boats, fishing gears, and other equipment, appropriate control measures (inspection, removal of attached mussels, drying, etc.) should be taken. For example, to prevent overseas transfer, mid-ocean exchange or suitable disinfection of ballast water is required. On the other hand, quite a few control methods have been developed. For example, in addition to direct removal methods (e.g. scraping, mechanical scrubbers in pipes), chemical control methods using anti-fouling paints and surfaces, metal-organic chemicals, chlorine, sodium hydroxide or potassium dichromate, are usually considered. Other control methods include oxygen deprivation, thermal treatment, air exposure and desiccation, manual scraping, high-pressure jetting, mechanical filtration, removable substrates, molluscicides, ozone, antifouling coatings, electrocution, radiation and sonic vibration. However, due to a number of technical constraints not all these methods are feasible. Biological control with toxic microbes and parasites is not very effective. Predation by migrating diving ducks, fish species and crayfish may just reduce mussel abundance, usually with short-term effect. In general, a combination of chemical and thermal procedures has proved particularly successful. In some cases, intake structures and piping have been directly built at depths sufficiently low to prevent zebra mussel colonisation.

Impacts of IAS on economic activities — damaging landscapes

Red palm weevil ***Rhynchophorus ferrugineus***

The red palm weevil

Species description

The red palm weevil is a 'snout beetles', a member of the family Curculionidae, the largest animal family with more than 60 000 species worldwide. It is a large reddish brown beetle about 3 cm long with dark spots on the upper side of the thorax and a characteristic long curved rostrum. The red palm weevil has strong wings and is capable of undertaking long flights. The adults are active during the day and night and can find their host plants at distances of several hundreds of metres. The complete life-cycle of the weevil, from egg to adult emergence, takes almost three months. Adult females lay an average of over 200 eggs in wounds along the trunk or in petioles, as well as in wounds caused by other beetles' larvae feeding on rotten wood (e.g. those of rhinoceros beetles). The larvae feed on the interior of the palm (in the bole, stem or different sections of the crown, depending on the age of the plant). After several months, before pupation, they reach a size of more than 5 cm. When about to pupate, larvae construct an oval-shaped cocoon of dried palm fibres, generally outside the trunk, at the base of the palms from which the adults will emerge.

Impacts

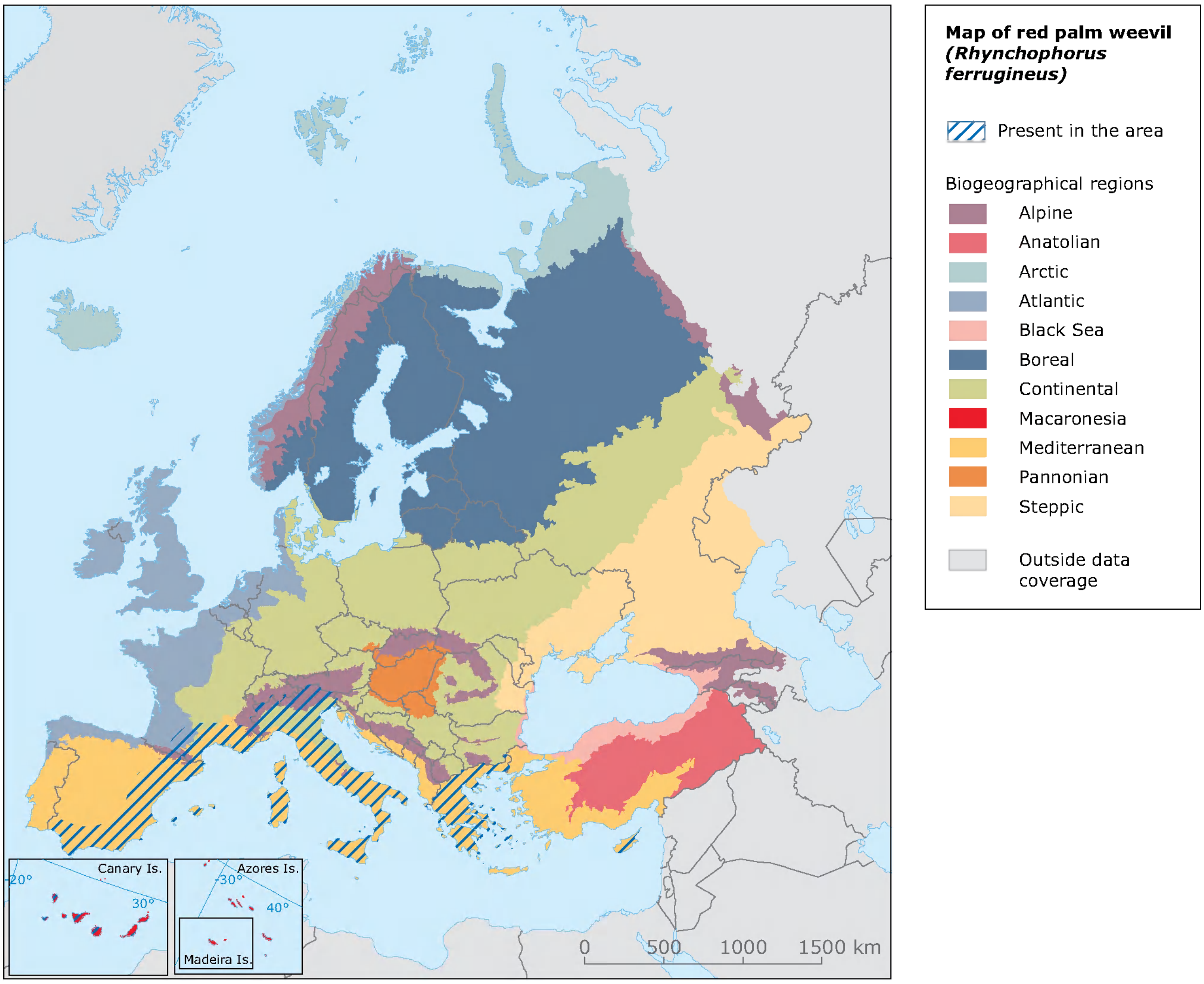
The red palm weevil is responsible for significant damage to a wide variety of palm species, such as the date palm and the Canary Island date palm, which are the two main crop and ornamental species in the Mediterranean area.

All Mediterranean countries which grow palms as amenity trees in the gardens and in the streets of towns and on sea fronts are particularly at risk. In fact, because date palms constitute one of the characteristic landscape elements in coastal cities, the death of individual trees can markedly impact the overall landscape perception. The date-producing countries also face serious risks, and the same happens to any other regions where palms are widely cultivated. For example, at Elche — a World Heritage Site by UNESCO in southern Spain — an outbreak of the red palm weevil is threatening the largest palm plantation in Europe.

Damage is produced mainly by the larvae, which move towards the interior of the palm by digging tunnels and large cavities in order to feed on soft fibres and terminal buds of hosts. They can thus be found in any place inside the palm. Serious infestations can obviously result in the death of the tree as the attack from larvae affects stems and growing points in the crown of palms, which often provokes the destruction of the apical growth area. A serious problem in the fight against this pest is the lack of sound techniques for early detection useful to guarantee weevil-free status in adult plants, or at least some effective treatments in the early stages of infestation. In fact, damages are usually visible only long after infection, when there is nothing to do to eliminate the pest and save the plant.

In India and Sri Lanka, this weevil is a serious pest of coconut and oil palm, while in Malaysia it affects the sago palm and in the Middle East the date palm. Moreover, it could also attack other ornamental palms as well as other plants, like *Agave americana* and the sugarcane.

Map of red palm weevil (*Rhynchophorus ferrugineus*)



Source: Based on Rabitsch, 2010.

Distribution and pathways

The red palm weevil originates from southern Asia and Melanesia, where it is a serious pest of coconuts. Since the mid-1980s this species has been rapidly spreading westward to the Middle East (e.g. Iran, the Kingdom of Saudi Arabia, Oman and the United Arab Emirates), Europe and North Africa (e.g. Egypt). The presence of the species has been recorded also in Australia, Papua New Guinea, Solomon Islands and Western Samoa. In Europe outbreaks in nurseries and public and private gardens have been reported in France, Italy and Spain (including a number of islands such as the Balearics, the Canary Islands, Corsica, Sardinia and Sicily), but also in Cyprus, Greece and Turkey. This weevil can be spread over long distances in infested plants for planting of host palms. Short-distance spread is possible by adult flight. However, movement of nursery stock and related international trade of plants for planting is considered the main pathway for the species.

Management

The rapid spread of the species and its relevant economic impact emphasise the urgent need of implementing strong preventive measures to avoid further spread and new outbreaks of this pest. Domestic phytosanitary measures can contain these outbreaks if weevils are detected sufficiently early. This can be guaranteed only by regular implementation of a mix of preventive and curative measures such as a survey of all cultivated gardens; cultural measures such as plant and field sanitation; preventive treatment of all the palms, even healthy ones; destruction of infested plant material and implementation of prophylactic treatment of cut wounds; and removal of adult weevils using pheromones lures and baited traps for mass-trapping (conventional light traps are not effective in attracting adults). A test based on the increase of the rate of transpiration and the reduction of diffusive resistance and water potential was also developed for detecting weevil-infested palms. In addition, the presence of larvae in the trees can be detected through the use of dogs or of specific electronic instruments capable of amplifying the low frequency of the noise made by the insect larvae.

Curative measures include trunk injection with insecticides; treatment of wounds with repellents and filling leaf axils with insecticide and sand; and drenching of the crown of infested trees with insecticides. There is no practical biological control at present and use of sterile insect techniques has been not feasible so far. However, an eradication programme lasting four years and carried out in Israel after an outbreak on date palms was detected in 1999, has apparently succeeded, showing that this pest can be contained and suppressed and eradication is a feasible target. In conclusion, it is also clear that as a key preventative measure, there is an urgent need for phytosanitary regulations to ensure that all imported plants for planting of palms originate in a pest-free area or pest-free place of production.

Impacts of IAS on economic activities — damaging landscapes

Horse-chestnut leaf-miner ***Cameraria ohridella***

The horse-chestnut leaf-miner

Species description

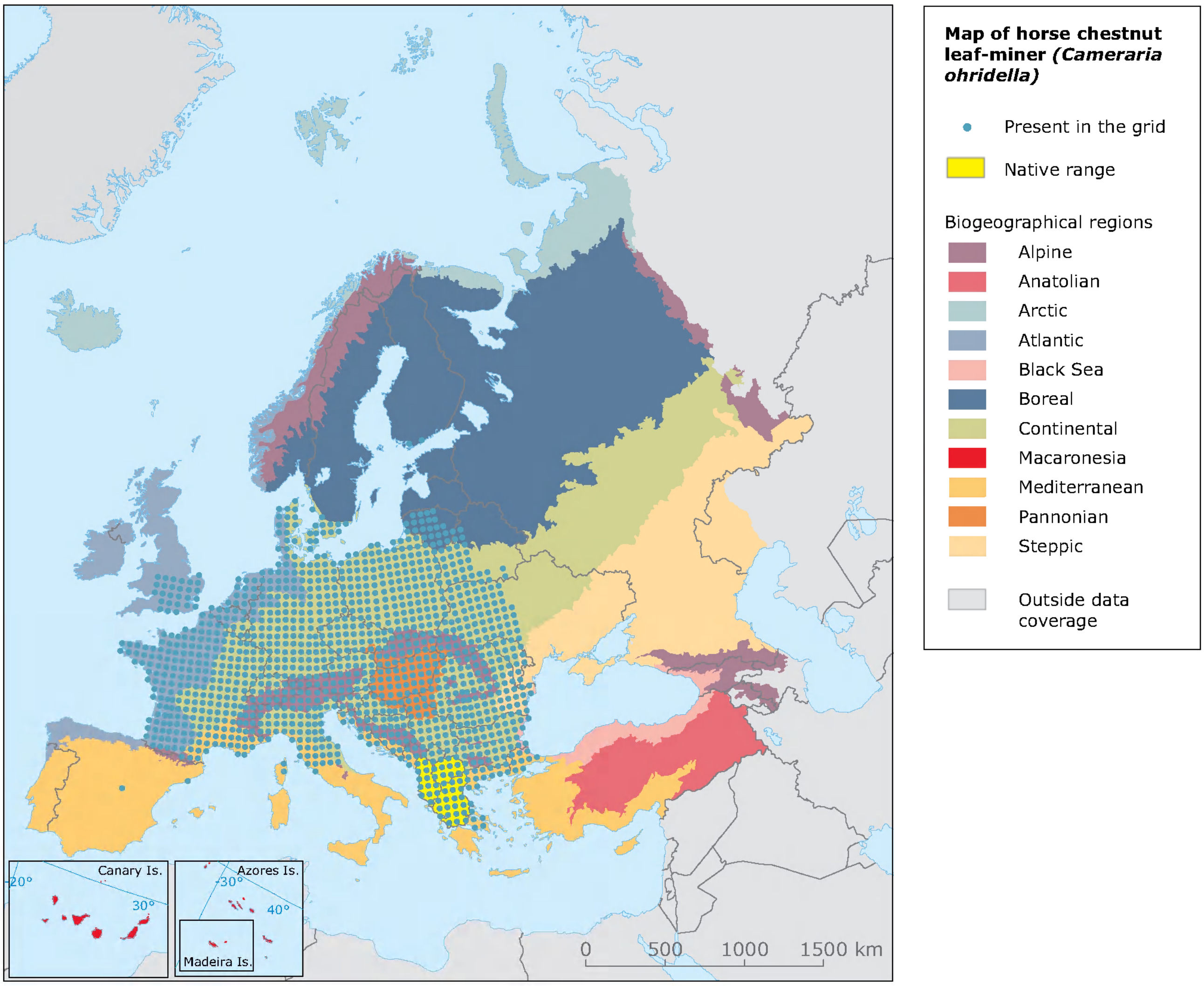
The horse-chestnut leaf-miner is a tiny little moth of 5 mm body size. It has colourful brown forewings with shiny, silvery stripes and grey hindwings with long fringes. Identification of larvae and adults is easy in most parts of Europe if found on its host plant, the white flowering horse-chestnut tree. This ornamental tree is widely appraised and planted in cities and parks in Europe since the second half of the 17th century. It is native to the Balkans. However, other leaf mining species feeding on other host plants look similar and records far from host plants need careful examination. The horse-chestnut leaf-miner hibernates in the pupal stage. Development of the adults is completed in spring when temperatures rise and the first generation appears as early as April in most parts of Europe. After mating on the bark of the trees, females lay up to 75 eggs on the upper side of the leaves. Larvae hatch after two to three weeks, drill immediately into the leave tissue and form a mine by feeding mainly on the palisade parenchyma. As a consequence, the upper epidermis above the mine is cut off from water supply and dies off. In contrast, the tissue below the mine remains functional. Damage is therefore visible as brown blotches on the upper side of the leaves only, while the lower surface of the leaves remains green. They pass through four to five larval and two prepupal stages before they pupate in the leaf mines around four weeks after they hatch from the egg. The larval feeding causes characteristic leaf mines that can cover almost the complete leaf area. The life-cycle is repeated — depending on outside temperature — three to four generations per year, until autumn pupae stay in the mine and overwinter in the dead leaves that fall to the ground. The pupae tolerate severe frost.

The horse-chestnut leaf-miner lives on the common white flowering horse-chestnut. In rare cases, it is able to complete its life-cycle on alternative host plants as well, such as some other chestnut species, Norway maple and Sycamore maple.

Impacts

The species is known to have both an aesthetic impact and a socio-economic impact. The feeding of the larvae causes significant damage to the leaves, including browning and premature leaf-fall. A single heavily infested tree can host up to 1 million moths. Although the moth is not able to kill trees, the vitality of horse-chestnut is reduced. A comparison of insecticide treated with infected chestnut trees revealed a total energy loss of 37 % over a growing season. Average seed weight, seed germination and relative growth rates but also carbohydrate concentrations and twig starch content decreased in infected trees. It appears that due to energy production early in the growing season, trees are able to cope with repeated infestations, but reproduction seems to be negatively affected most. Although this is not a particular problem for ornamental trees, it may be more serious for the native horse-chestnut populations in the Balkans, if their reproduction is declining. Horse-chestnut is widely planted in European urban habitats, and aside from the negative aesthetic impression of infected trees, and possible nuisance to people sitting below these trees in parks and gardens, the loss of photosynthetic activity also decreases positive effects of trees in cities, such as climate and air regulation. The executed management activities by city authorities cause economic damage, but no estimates about the magnitude are yet available. There are no positive effects of this moth species reported in the introduced range.

Map of horse-chestnut leaf-miner (*Cameraria ohridella*)



Source: Based on Augustin, 2008.

Distribution and pathways

The origin of this species is under debate since it was first detected at Lake Ohrid in the former Yugoslav Republic of Macedonia in 1984, because it is the only representative within the genus in Europe. The centre of diversity of the moth genus is situated in America and of the host plant genus in East Asia. Because the horse-chestnut has its origin in the Balkans, it was assumed that the leaf-miner originates from the Balkans as well. Recently, with the help of molecular tools, there is evidence that the horse-chestnut leaf-miner may indeed have its origin in the Balkan area. Moreover, the leaf-miner was preserved in old chestnut herbarium sheets, collected in 1879 in Greece, proving the existence of the moth in the Balkans for far more than 100 years. Genetic data further indicate that only 3 of the 30 known haplotypes of the species spread over Europe, with one dominating (invasive) haplotype.

The spread of the species started soon after its discovery at around 60 km per year, aided by passive transport with vehicles along motorways and major roads. There are two relevant dispersal mechanisms: adult flight and transportation with current winds over short distances and translocation with vehicles over long distances. It is impossible to park your car under an infested chestnut tree and not translocate dozens or even hundreds of this creature when continuing your journey. Today, the species has spread over large parts of Europe and it does not seem as if the spread has yet come to an end, particularly in eastern Europe. It appears that the horse-chestnut leaf-miner does not tolerate too high temperatures, which is why it is speculated that it is still absent in large parts of Spain and southern Italy.

Management

A simple method is the removal of leaf litter in autumn, in which pupae hibernate. The litter should be composted, if litter burning is forbidden. The application of insecticides and developmental inhibitors (dimilin) is effective, but should be executed with utmost care considering safety regulations to minimise side-effects on non-target species. Because trees are not killed, and able to re-flush again, cutting usually is not necessary. Much effort was laid on finding specialised parasitoids that can serve as biological control agents to control the moth. Despite some progress, no parasitoid species are currently known that are able to suppress the damage below an acceptable threshold. The same is true for natural predators, such as some birds, bush crickets, ants and lacewings, which feed on the larvae, but are not able to significantly reduce moth populations. Indeed, the lack of natural predators and parasitoids can be seen as one reason for the great success and rapid spread of the moth. There are indications that the number of generalist parasitoids, mostly chalcid wasps, increased recently.

Impacts of IAS on economic activities — damaging agriculture and forestry

Grey squirrel *Sciurus carolinensis*

The grey squirrel

© Photo courtesy of Sandro Bertolino

Species description

Grey squirrels are among the most successful IAS. They are medium-sized tree squirrels, about the size of a small cat, characterised by a predominantly grey fur with cinnamon tones and a white to pale grey tail and underside (with no sexual dimorphism in size or colouration). Grey squirrels are well adapted to live in broadleaved woods and spend most of their time on the ground, but can also colonise conifer and mixed forests. They feed mostly on nuts, flowers, buds, fruits, fungi, some insects and occasionally bird eggs, while they are preyed upon by a range of small to large carnivores, for example minks, red foxes, wolves and several birds of prey, such as sparrowhawks and Tawny owls.

Impacts

The grey squirrel introduced to the British Isles and Italy represents a well documented case of an alien species impacting both the agriculture sector and the forestry industry, as well as causing ecological damage to forest ecosystems. In Britain the impact to the agricultural sector could be significant, particularly in arable crops, orchards and market gardens if they are located favourably for the species habitats, and if availability of other food sources is limited. On the other hand, in Italy it seems that damage to agricultural crops, mostly maize, is not a significant issue.

The grey squirrel is responsible for causing extensive damage to woodland through bark stripping activity that exposes the timber to fungal and insect attack, disrupts the flow of nutrients up the tree and weakens the stem. The presence of grey squirrel can thus affect the re-growth and natural tree reproduction in forests, thus threatening species of the native fauna, and potentially ecosystem functioning (bark-stripping of selective tree species could also change the composition of forests or hinder the establishment of new woodlands; moreover it could have a potential impact on nesting birds). In Italy, the species can have significant economic impact on maize, hazelnut crops, poplar plantations and, potentially, vineyards. It is also reported to be a garden pest by digging up bulbs and eating the bark of ornamental plants, and can damage properties, for example by chewing timber and wires and stored goods, tearing up insulation and building dreys in lofts.

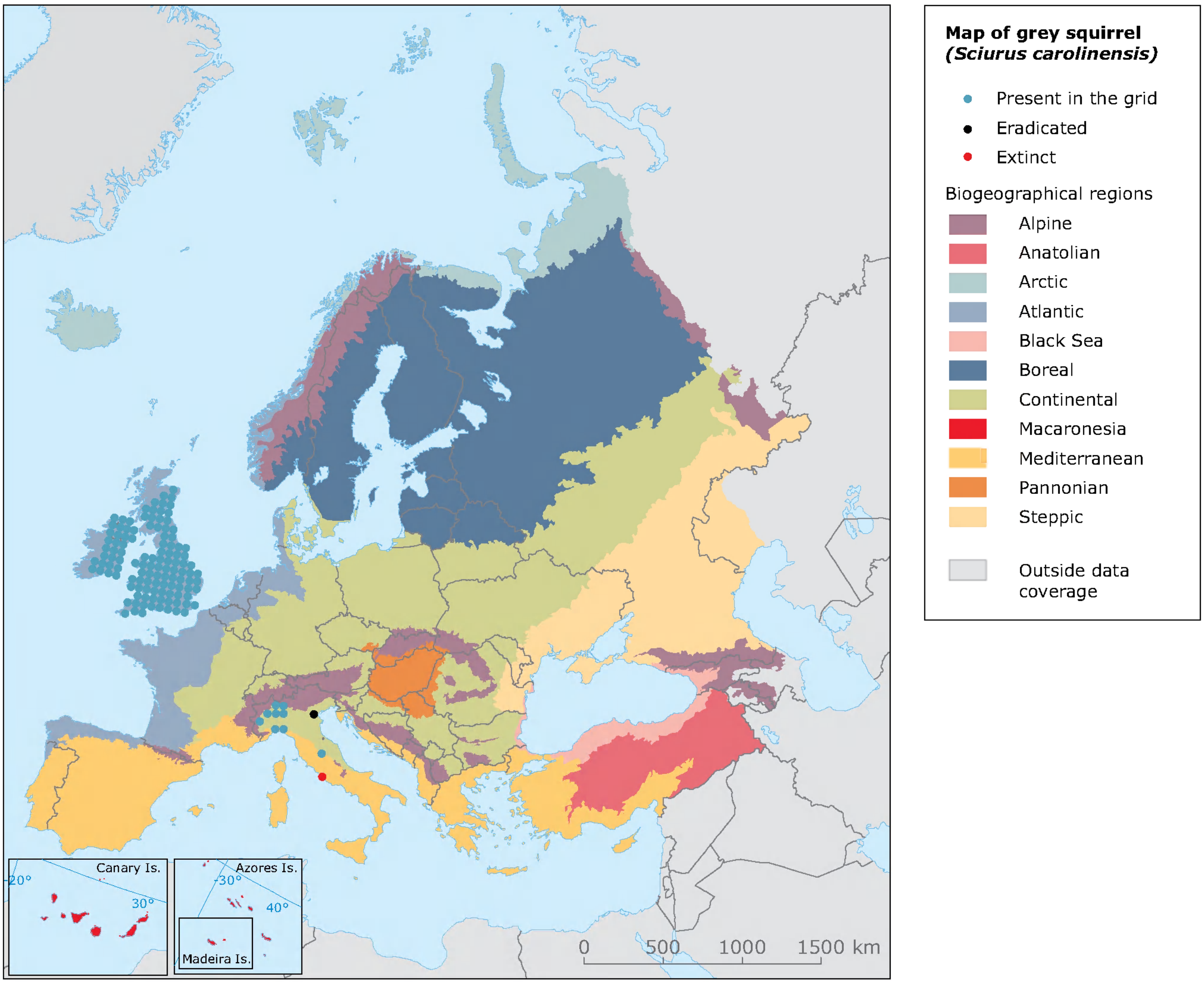
In the United Kingdom, where it is believed that there are over three million grey squirrels, damage to forestry is also huge, with an estimated reduction of the value of tree crops by about 25 % or GBP 10 million per year, while the estimated current annual control cost for timber protection is over GBP 5 million per year.

The grey squirrel out-competes the native red squirrel in all overlapping areas in Britain and Italy. The rapid increase of the grey squirrel's distribution range coincides with a dramatic decline of the range of the native red squirrel in all invaded areas. Interspecific competition seems to occur mainly for food resources that affect fitness of red squirrels at crucial periods of the year, when resources become limiting. The impact of the grey squirrel on the red squirrel is also facilitated by a lethal disease, the *poxvirus*, which is fatal to red squirrels (and potentially transmissible to humans) but benign to grey squirrels.

Distribution and pathways

The grey squirrel is a North American species, originally distributed from the Gulf of Mexico to the southern part of Quebec and Ontario. It is currently introduced in many localities of Europe, North America and South Africa (in Australia it is now extinct). In Europe it has been introduced to Great Britain, Ireland and Italy on several occasions since the end of 19th century. At present, the European range covers most of England and Wales, the southern part of Scotland, and the eastern part of Ireland. It is also present with several populations in northern and central Italy. Besides the known range in Piedmont, Lombardy (many areas) and Liguria (in Genova) the species has also been recently reported in the Apennine in Umbria, Perugia. In most of the cases, the animals were imported and deliberately introduced for ornamental purposes into parks, woodlands and estates. There is a high probability that self-sustaining populations develop from only a few released individuals (e.g. the oldest grey squirrel population in Italy originated from four to six animals). The species was also known to occur in a site in the Padua province, Veneto, where it was promptly removed in 2009, and in Rome, in an urban park where it was probably removed by predation from feral cats in the 1980s. Today the grey squirrel populations are constantly

Map of grey squirrel (*Sciurus carolinensis*)



Source: Based on Genovesi and Scalera, 2008c.

expanding both in the British Isles and in Italy, from where in the next decades it is expected to colonise France and Switzerland. This range expansion is the result of natural dispersal of the species, facilitated by wooded corridors. The increasing number of populations is due to releases or escapes of animals bought as pets. For this reason several countries have banned the trade of the grey squirrel. The grey squirrel is predicted to expand over a large portion of Eurasia in the future.

Management

The spreading populations in northern Italy are a major threat for the conservation of the native red squirrel on the entire European continent. In the United Kingdom intensive control is regularly carried out by a number of means, including trapping, nest destruction or drey-poking, shooting and poisoning with anti-coagulants. However, in Italy early attempts to eradicate the species in 1997 failed because of strong opposition from animal rights groups who took the case to court and managed to halt the intervention. Although the case was closed in 2000 with the full acquittal of those responsible for the eradication programme, the suspension of the actions allowed the species to significantly expand its range so that eradication is no longer considered feasible.

However, it is still possible to act. According to simulations, the eradication of the two populations of Genova and the Ticino river would postpone the invasion of central Italy and Switzerland for at least one century. For this reason, a LIFE project (EC-SQUARE) started in 2010 with the aim to stop the spread of the species in Italy. Nevertheless, grey squirrels are still sold in pet shops and as a result of further releases/escapes from captivity several new cases of grey squirrel occurrence in parks and woods have been reported over the past decade (as in the case of some small nuclei recently recorded in Lombardy). The import of the grey squirrel has been recently suspended by the EU Wildlife Trade Regulations on the grounds that it poses an ecological threat to indigenous species.

Impacts of IAS on economic activities — damaging agriculture

Rose-ringed parakeet *Psittacula krameri*

The rose-ringed parakeet

© Photo courtesy of Riccardo Scalera

Species description

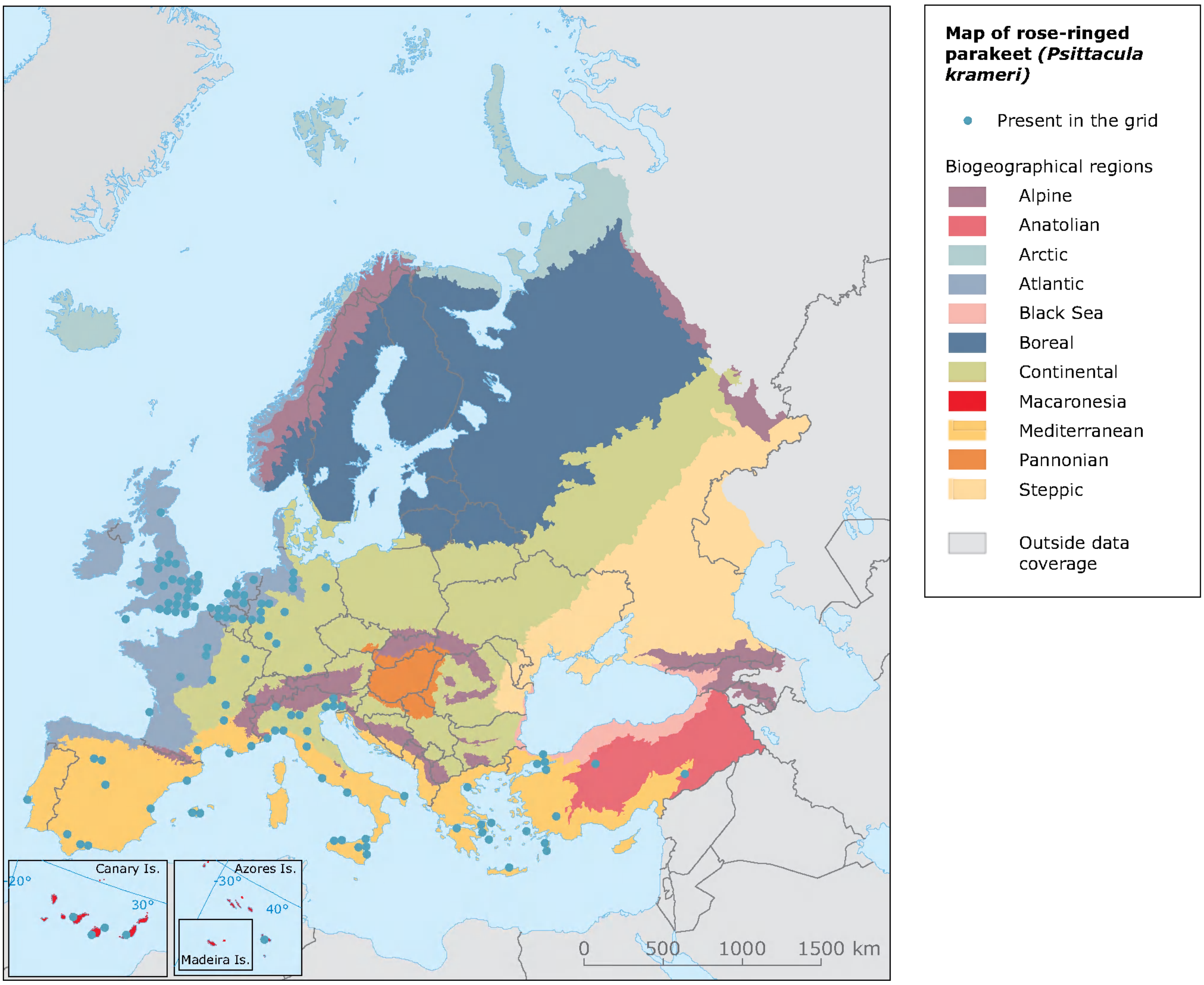
Parrots are present in Europe only as a consequence of several introduced species that have recently created breeding colonies further to intentional releases or accidental escapes. This is the case of the rose-ringed parakeet, a medium-sized, slim, bright yellowish-green bird, about 40 cm long, of which the very long tail accounts for more than half. Males are characterised by a black and rose or light red band which encircles the neck, joined to a black bib that extends up to their red bill, while females have just an indistinct emerald ring. In Europe this species is found mostly in urban or suburban habitats, such as parkland, but in its native range lives in tropical and subtropical lightly wooded habitats too. It can be found in a wide range of temperatures, precipitation, and light regimes in anthropogenic-influenced habitats that provide sufficient food resources. The rose-ringed parakeet is a generalist feeder, consuming a variety of fruits, flowers, nectar, cereals, grain and seeds, depending on availability during the year. In Europe this species shows a great deal of plasticity in its feeding behaviour, as besides fruit, flowers and seeds of a number of trees, it also feeds on leftovers of bread, bacon and other meat. Moreover, it seems to depend to a certain extent on garden bird feeders during winter, consuming large quantities of peanuts and sunflower seeds. The frequent loud screeching calls typical of this species are becoming a familiar sound in many European cities, particularly in parklands. Roosting sites are sometimes spectacular, as they may often contain several thousand birds attracted from a wide area to just a few trees.

Impacts

In at least part of their native range the rose-ringed parakeets are considered one of the most destructive bird pests for agriculture. In India and Pakistan, for example, there are extensive reports of crop damage. In this region rose-ringed parakeets are known to feed on a wide variety of agricultural cereals (such as sorghum and maize), pulses (such as black gram), oil seeds (such as sunflower), dates and other fruit orchards. In India, depredations by rose-ringed parakeets on maize and sorghum crops have been considered responsible for major yields reductions, by up to 81 % and 74 %, respectively. In Australia, rose-ringed parakeets are known to cause severe damage to plantations by stripping the bark from young stems and killing the affected trees, thus locally changing the arboreal composition. In Europe most rose-ringed parakeet populations were initially introduced in urban environments, thus the impact on agriculture has been historically limited. However, they are now extending their range into rural environments, thus increasing the potential to become agricultural pests. Although the reports of parakeet damage to agriculture are still few, there is clear evidence of significant damage to crops as well. Moreover, the potential for the parakeets to become serious pests in the future has been highlighted. For example, in the United Kingdom rose-ringed parakeets damage buds and blossoms of various trees and shrubs. For this reason conflicts are known with fruit growers that experienced damage to apple, pear, cherries and plums. In addition, this parakeet has been reported to have damaged vineyards by reducing the expected wine production.

Rose-ringed parakeets may have detrimental effects on native birds with which they may compete, particularly in those habitats where the number

Map of rose-ringed parakeet (*Psittacula krameri*)



Source: Based on Shirley and Chiron, 2008c.

of cavities as breeding sites is a limiting factor regulating population densities of cavity-nesters. The most vulnerable species in this regard is the Eurasian nuthatch, but nest-site displacement could affect also common kestrel, stock dove, western jackdaw and common starling. Effects on rare cavity-nesting birds are however not yet properly documented.

Rose-ringed parakeets are also possible vectors for diseases, like Newcastle's disease and cryptosporidium, which could be harmful to poultry and might also have an impact on that industry. Moreover, they could affect humans in the case of psittacosis. Finally, in some residential areas they could be a noise nuisance.

Distribution and pathways

The rose-ringed parakeet, native to the African continent south of the Sahara and to south Asia, is now the most widely introduced parrot in the world. In Europe, it is introduced in at least 12 countries, from Belgium and the United Kingdom in the west, across north-central Europe to Greece and Slovenia. Both population size and distribution are increasing in several countries in western Europe (Belgium, the Netherlands and the United Kingdom) as well as in Israel and Turkey. Rose-ringed parakeets were highly traded as a cage bird during the late 1960s and 1970s and most introductions occurred as a result of escapes or releases from aviaries.

Management

Given the actual and potential economic and ecologic impacts, it would be useful to monitor existing wild and captive populations, and to improve legislation to prevent deliberate introductions and escapes (but also to ban inclusion of this species in captive collections). Moreover, depending on the risks posed, population control or eradication may be considered necessary to limit the spread of the species and the potential for further damage. The possible methods available to control rose-ringed parakeets include egg and chick removal (even with the use of nest box traps); poisons or stupefying bates; fertility control agents; shooting; and trapping. All methods have both advantages and disadvantages; for this reason the most effective population control is likely to result from the combined use of a number of methods rather than reliance on a single one. However, the fact that large numbers of birds are concentrated primarily in urban parks and gardens can be a major constraint, for example for the applicability of the control method. In addition, the removal of parakeets could attract considerable attention from the public, in particular bird lovers, which may first need to be convinced that control is necessary. If the parakeet population continues to expand and to provoke increasing damages to crops and native fauna, farmers and conservationists would certainly support the control of populations, whilst there are always some risks that animal rights groups and some members of the public would oppose lethal methods of control.

4 Scenario for the future

Because of the increasing trends in the global movement of people and goods, the number and impact of harmful IAS in Europe might grow significantly in the future. Through their impacts on species and ecosystem processes, IAS can result in the fragmentation, destruction, alteration or complete replacement of habitats, which in turn can have cascading effects on even more species and ecosystem processes. Further invasions will be facilitated by increased global trade and travel interacting with effects of increased habitat loss and climate changes. For this reason some scientists argue that biological invasions should even be managed as natural disasters. Thus, preventing the harmful impacts of IAS will have to become even more a fundamental requirement of any conservation strategy at both the European, national and local levels. In parallel, a higher level of awareness of IAS impact and a stronger commitment to addressing this threat will certainly be a sensible achievement.

Experiences regarding the impacts of past invasions clearly suggest that the implementation of sound preventative measures could have reduced some of the major impacts of IAS in Europe. On the other hand, for all these IAS already (or newly) established and likely to have a substantial negative ecological, social or economic impact, it would be crucial to promptly react through implementation of the most appropriate and effective management measures. The best way to deal with this threat is through a combination of preventive measures, early detection and rapid response to new incursions, with permanent management only as the last option. There are, on record, an increasing number of successful attempts to remove the most harmful IAS, with over 1 000 eradications successfully completed worldwide. In many cases, these actions contributed more than any other conservation action to the recovery of threatened species, and to reducing biodiversity loss. For example, the conservation status of 11 bird, five mammal, and one amphibian globally threatened species has improved as a direct result of eradication programmes (McGeoch et al., 2010). These successes demonstrate clearly that threats from IAS can be mitigated and that biodiversity can be protected through these actions. Tackling IAS also addresses the economic damage they cause and the serious threats they pose to human communities, for example through reducing access to food and water or spreading diseases.

Several invasions of IAS now threatening the region's biodiversity, health and economy might have been stopped if rapid action to eradicate or at least control these species following their detection had been appropriately undertaken. Unfortunately, due to a lack of information and awareness, and in the absence of comprehensive and harmonised legislation at the European level, the issue of IAS and their impact is often underestimated (especially for species that do not directly damage agriculture or human health) and adequate prevention and mitigation measures are thus lacking.

However, it is clear that given the current level of inaction, in many though not all European

Eradication programmes are in general very effective conservation measures. Nevertheless, some drawbacks have been reported in situations where an introduced species (e.g. the cat) has been removed without taking into proper account the presence of other introduced species (such as rabbits, rats or mice). The risk is that some problems linked to hyperpredation and predator release effect may create trophic cascades leading to rapid, landscape-wide ecosystem changes. For example, on the sub-Antarctic Macquarie Island, the removal of cats resulted in a significant increase in rabbit abundance (formerly reduced by cat predation), which led to substantial local- and landscape-scale changes in vegetation. Although this trophic cascade was predictable given the history of rabbit impacts via grazing on both this and other islands and was not entirely unexpected, its extent was not fully anticipated (Bergstom et al., 2009). This episode shows the importance of carefully assessing the risks of management interventions and planning for their indirect effects.

countries and/or not all situations, the impact of IAS is becoming increasingly harmful. The ongoing invasion of **grey squirrel** in Italy is a good example of such shortcomings. In fact, all predictive models agree that if no control or eradication actions are undertaken in the northern populations of the Italian peninsula, grey squirrels may invade France and Switzerland within the next 15–70 years and colonisation of the rest of Europe is only a matter of time. According to simulations, eradication of the two populations in Genova and the River Ticino would help to postpone the invasion of Switzerland and central Italy by about 100 years. This situation also shows the importance of transnational cooperation within Europe. In fact, with the continent's shared coastline, transboundary mountain ranges and international watercourses, species introduced into one country can easily spread to neighbouring countries. The development of a comprehensive and effective European strategy on IAS including an early warning and rapid response system supported by a sound legislative framework at both the regional and local levels would certainly help overcome similar problem.

4.1 Effects of increasing trade and tourism

Globalisation and economic growth are widely recognised as important drivers of biological invasions. Consequently, there is an increasing need to address the role of international trade in strategies to prevent the introduction of new IAS. The role of different types of commerce in the movement of IAS worldwide is quite well understood. There is in fact a vast array of trade-related activities that cause the movement of species, and consequent introduction of IAS. Such activities range from direct trade of live animals and plants as food, to movement of marine and freshwater species for aquaculture, commerce with pets and horticultural species, to the movement of species for research, fur farming, hunting, angling, etc. The associated impacts are, in part, a cost of the way society has chosen to organise its trade. Globalisation — opening new trade routes, increasing trade with new partners and new commercial products, expanding tourism — increases opportunities for potential IAS to be moved between continents and into, within and from the EU. This is not surprising if we consider that more than 90 % of world trade is carried by sea and by 2018, the world fleet could increase by nearly 25 % with volumes nearly doubling compared to 2008. On the other hand, the number of travellers crossing international borders every year is approximately 650 million. Subject to the current economic crisis, EU maritime transport is predicted to grow from 3.8 billion tonnes in 2006 to 5.3 billion tonnes in 2018. Forty per cent of intra-European freight is already carried by short-sea shipping and over 400 million sea passengers pass through European ports each year. Thus, the vulnerability to biological invasions of many European countries is also enhanced by the openness of the EU economy and the peculiarities of its trade routes, in association with the overall importance of the agriculture, forestry, fishery and tourism sectors at the regional level.

Given the increasing role of global trade and movement of individuals in the introduction of IAS, and the wide range of related introduction pathways, a sound legislation is critical to support whatever preventative measures are necessary. IAS-related measures aimed at safeguarding biodiversity (besides preventing damage to trade and economic interests) could be strengthened by improved coordination between the different national authorities/key stakeholders, and in terms of IAS inspection capacity, and could benefit from reinforced controls at hubs (airports, harbours) and other relevant entry points. To this purpose, adequate resources should be allocated for deployment of appropriate detection aids (scanning equipment, trained sniffer dogs for baggage, etc.) and powers for the seizure and destruction of specified consignments. Some targeted capacity support (e.g. identification and taxonomic guides) and training (e.g. national and regional workshops) would also be needed.

Recent studies have demonstrated that many of the most problematic IAS are not recent arrivals but were introduced several decades ago. Hence, current patterns of alien species' richness and relevant impacts may better reflect historical rather than contemporary human activities, a phenomenon which might be called 'invasion debt' (Essl et al., 2010). Thus, the consequences of the current high levels of socio-economic activity on the extent of biological invasions will probably not be completely realised until several decades into the future. This should be taken into account in the planning of any management strategy.

4.2 Double trouble: Climate change and IAS

Rising concentrations of greenhouse gases released into the atmosphere by human activities are changing the climate. Global climate change has many environmental consequences. Under climate change, some species (either native or alien) are expected to decline while others will thrive. For example, in case native species are no longer adapted to the changed environmental conditions in their native range, it is likely that other introduced species will displace them. Climate change might thus produce more favourable conditions for IAS and new opportunities for them to proliferate and spread. For this reason the combined effect of climate change and IAS has received growing attention in the last years.

Other possible consequences of climate change for IAS include altered distribution and impact of existing IAS, altered transport and introduction mechanisms, establishment of new IAS, and altered effectiveness of control strategies. In terms of impact, there is also a concrete risk that in this situation some IAS will initiate complex, unpredictable cascades of effects. For example, many IAS are generalists and highly adaptable, able to tolerate or take advantage of changes and disturbance. For this reason, IAS are expected to cause even more harm under climate change. Species that currently are regulated by cold winter temperatures, for example the **coypu**, may increase in abundance due to mild winters and reduced mortality.

Another issue that puts the impact of IAS in relation to climate change is the increased use of biofuels as an alternative to fossil fuels. Human responses to climate change are likely to provide new invasion opportunities for biofuel crops, which may be planted on a large scale and usually consist of fast-growing, highly competitive plant species. For example, the 2009/28/EC Renewable Energy Directive (RED) endorses a mandatory 10 % minimum target to be achieved by all Member States for the share of biofuels in transportation by 2020. However, one emergent problem of biofuels — in addition to others such as land use change, deforestation and displacement of indigenous people — is related to the risk that such crops might become invasive, with the potential to spread and cause harm. In fact, several biofuel crops share traits with IAS. Indeed, some biofuel crops have the potential to escape from cultivation, given that they are 'selected' mainly for their efficiency in seed set and biomass production. This factor together with the particular susceptibility of agro-ecosystems to invasions and the peculiarities of the cropping system increases the potential for invasive spread of biofuel species. An example is the **knotweed**, an invasive weed considered for planting as a biofuel plant, which might increase its impact further in the future. For this reason, biofuel crops should be subject to specific risk assessments before cultivation is considered. These are just a couple of examples of the possible negative effects of using IAS in climate change remediation projects. In fact, it would be very important to accurately evaluate the potential of policy models that would explicitly link the cultivation of biofuels with forest conservation as part of the United Nations Framework Convention on Climate Change (UNFCCC), as well as the related agreement to develop a mechanism to provide incentives to tropical countries for reducing emissions from deforestation and forest degradation (REDD+ programme).

Some IAS are expected to thrive and proliferate thanks to new opportunities offered by extreme weather events, and changing weather patterns (e.g. reduction in winter frost severity). Extreme events such as floods, droughts and fires may serve as major triggers for biological invasion by killing or displacing native species, by facilitating the escape of potential IAS from captivity and by aiding dispersal of IAS in general.

Native species and ecosystems stressed by climate change will be less competitive and more vulnerable to threats by IAS. Stressed amphibians, for example, appear more vulnerable to diseases such as chytridiomycosis caused by the **chytrid fungus** *Batrachochytrium dendrobatidis*.

Finally, other combined effects of climate change could be those related to the recent discussions on 'assisted colonisation'. This management option is receiving renewed interest in the light of predicted impacts of climate change on endangered species. Yet, it is creating a growing concern among invasion biologists who have issued a strong warning about the risks of moving declining species to new locations in an attempt to save them from the effects of climate change, dubbing such moves 'planned invasions'.

5 Towards a bioinvasion impact indicator

Following increasing recognition of the impacts of IAS over the last decade there have been several attempts to develop indicators of biological invasions. Indicators have been developed across a range of spatial scales and have been based on a range of measures. The EEA has provided a major contribution to this through the 'Streamlining European 2010 Biodiversity Indicators' (SEBI 2010; EEA, 2012) project. The SEBI 2010 was set up as a process to assess progress toward the target of halting the loss of biodiversity by 2010. With regard to IAS, a response indicator measuring the 'Trends in invasive alien species in Europe' was developed as part of the work of the SEBI 2010 process. This indicator was made up of two elements:

1. cumulative number of alien species in Europe since 1900;

The central American *Opuntia* and *Agave* in a tourist site in Corsica, France.

2. worst IAS threatening biodiversity in Europe.

Until recently, there have been very few examples of indicators of invasion that are based on a broad coverage of groups, large spatial scales, including temporal trends or considering impacts of IAS. One of the most crucial issues in the development of indicators — besides treatment of geographic and taxonomic bias in data availability, and the accessibility of data and problems associated with expert opinion — is the problem of classification of an alien species as invasive. The difficulties of designating alien species as invasive are complicated by the use of a wide range of definitions and criteria. For example, the Convention on Biological Diversity (CBD) defines IAS as 'a species outside of its native range whose introduction and/or spread threatens biodiversity.' This definition does not explicitly include alien species affecting economies and human health, although the CBD definition of biodiversity does make reference to the ecosystem services (and thus could cover the effects of IAS on human livelihood).

The unclear definition of invasiveness could represent a major constraint for the development of reliable indicators based on the impact of IAS, and might compromise the comparability of future indicators from the regional to the global scale. The confusion in invasions terminology is primarily due to the different concepts of invasiveness, based on either biogeographic or impact criteria. Another difficulty in identifying an alien species as being invasive is due to the lack of data on both invasive and native species, difficulties in the detection of impacts and unclear criteria for interpreting what constitutes an impact. The result is that alien species' invasiveness tends to be underestimated because of lack of data and this could be misinterpreted as the species not being invasive, which may well be misleading. This lack of methodology and of information represents a major shortcoming, because the quantification of the impact of different IAS would allow for prioritising actions against the most harmful or with the highest potential of becoming established or spreading.

Assessing the EU contribution to tackle IAS

Although no specific legislation on IAS has been established so far in the EU, measures aimed at either preventing or mitigating their impact have been financed and implemented, especially in countries that have experienced huge damage to biodiversity and socio-economy. As shown by an EEA study (Scalera, 2008), the LIFE programme has been an important financial instrument used to carry out concrete actions against IAS in the EU. Through this instrument, from 1992 to 2006, the European Commission financed 187 projects totally or partly dealing with IAS for a total budget of more than EUR 44 million. The EU is funding projects addressing IAS also through programmes other than LIFE. For example, the RTD Framework Programmes have funded several important projects focusing on IAS impact. The renowned acronyms ALARM, IMPASSE and DAISIE are only a few of the 90 research projects dealing entirely or in part with IAS that the EU has funded during the period 1994–2006, with a total budget of more than EUR 88 million.

The costs for measures planned or undertaken to face the IAS threat are directly related to the relative level of damage costs, and as such can be considered a factor useful to calculate the monetary value of their socio-economic impact. A study funded by the EEA within the SEBI process has provided some elements to contribute to the development of a response indicator expressed by the measures of the budget spent for management and research activities for IAS. The study has highlighted a positive trend over the years 1992–2006 of both the number of projects funded and the level of budget spent under the LIFE and the Research and Technological Development (RTD) Framework Programmes. Such trends might indicate an increasing awareness of the problem among wildlife managers and scientific institutions and an increasing willingness to pay by EU institutions and citizens, but also that the impact of IAS within the EU is increasing. Therefore, such results may contribute to assessing the economic impact of IAS in Europe, at least indirectly, in terms of costs for reduction and/or prevention of damages.

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Annex 1 Index of species

List of all species mentioned in the text or described in the dedicated species account, followed by the relevant scientific names.

Annex 2 List of acronyms and abbreviations

AWACS	Airborne Warning And Control System
CBD	Convention on Biological Diversity
COP	Conference of the Parties
DAISIE	Delivering Alien Invasive Species Inventory for Europe
EEA	European Environment Agency
EPPO	European and Mediterranean Plant Protection Organization
H5N1	Influenza A virus (subtype)
IAS	Invasive Alien Species
IUCN	International Union for Conservation of Nature
KUCORPI	Klaipeda University, The Coastal Research and Planning Institute
LIFE	L'Instrument Financier pour l'Environnement
NOBANIS	European Network on Invasive Alien Species
OIE	World Organization for Animal Health
RED	Renewable Energy Directive
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RTD	Research and Technological Development
SEBI 2010	Streamlining European 2010 Biodiversity Indicators
SSC	Species Survival Commission
UNESCO	United Nations Educational, Scientific and Cultural Organization

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