Chapter 10
Invasive Alien Species and Their Indicators

Robert H. Armon and Argyro Zenetos

Abstract Biodiversity is obstructed not only by climate change but also, among other factors, by invasive alien species (IAS). The infiltration/invasion, overgrowth, and control of IAS is linked to many elements, such as human activities that change our environment in such a way that, together with climate change, new opportunities for alien species to conquer new territories are realized. The successful take over by IAS of new geographic areas is orchestrated by the ability to grow fast and spread rapidly without "real competition." The environmental/ecological impact of IAS has still to be defined; however, there is plenty of research that can be performed to assess this facet. Presently, the global awareness of IAS is rising, as expressed in the many international committees/organizations looking for IAS's indicators and economical solutions to the problem.

Keywords Invasive alien species (IAS) • Invasion • Tropicalization • Climate change • Streamlining European Biodiversity Indicators (SEBI) • Delivering Alien Invasive Species Inventories for Europe (DAISIE) • Marine Strategy Framework Directive (MSFD)

10.1 Introduction

Perhaps the most invasive species known to science today is the human race. Starting ~200,000 years ago somewhere in Africa, our species conquered almost every territory/niche on this planet. Like all invasive species, humans developed two main characteristics of an invasive species, that is, the ability to: (1) grow in diverse ecological niches, and (2) reproduce successfully. As seen later in this chapter, the human invasion has both positive and negative aspects. To justify our

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impact on our environment, our entrance into the history of the universe brought amazing positive developments (i.e., computer technology), control over some parts of the nature (i.e., agriculture), and control over other organisms (i.e., disease control), although coupled with some highly negative aspects such as wars (i.e., self-destruction), pollution, annihilation of other species, and overcrowding of the planet earth! The present chapter is not intended to describe the human species as such but rather to describe other organisms that have invaded our environment and the methods using specific indicators that we are expecting to use to allow us to issue warning about them. However, we must bear in mind that we constitute a very important, sometimes even crucial factor, in species invasion.

From the historical point of view, almost all cultivar plant species are invasive species spread mainly by humans! Most of our edible plants have been transferred from one place to another along the centuries in parallel with human global colonization, e.g.: the potato (*S. tuberosum* sp.), domesticated in Peru-Bolivia and later brought to Europe; the tomato (*Solanum lycopersicum* sp.), a native of South and Central America subsequently distributed all over the world; maize (*Zea mays subsp. Mays*), domesticated in the Tehuacan Valley of Mexico and later dispersed globally; and wheat (*Triticum* spp.), originally cultivated in the Near East and Ethiopian Highlands and now disseminated globally. It should be pointed out that the spread of and invasion by an organism is controlled by several factors: (1) distance; (2) climate; (3) nutrient sources; and (4) genetics. It is clear that an endemic plant growing in one continent has to be transported to another continent in order to prosper and invade. Nevertheless, when dealing with motile or marine organisms (birds, mammalians, fish, crustaceans, etc.), transport is facilitated by their motility without direct human intervention (Fig. 10.1). Therefore the invasion process should be defined carefully in order to distinguish it from other ecological processes. Basically, species invasion should be examined from our perspective and linked to the environmental/ecological balance and its beneficiary/detrimental impact (Kelly and Hawes 2005; Whitman 2000).

The definition of the term ‘alien’ species varies (Warren 2007). Alien: an organism occurring outside its natural past or present range and dispersal potential, whose presence and dispersal is due to intentional or unintentional human action. In Europe, natural shifts in distribution ranges (due, e.g., to climate change or dispersal by ocean currents) do not qualify a species as an alien (Ojaveer et al. 2014). In contrast, immigration due to climate changes is considered biological invasion in USA. Invasive species are a subset of those alien species that are established and have an impact (positive or negative) on ecosystems and/or ecosystem functioning.

In Europe, invasive species are defined as species that are external to their natural distribution and also threaten biological diversity (EEA 2012; Genovesi et al. 2012; Anonymous 2011a). There are additional definitions, such as that which relates to native species able to overspread in the absence of natural control (deer, family Cervidae) or that which relates to a species that is globally widespread and therefore is considered non-indigenous to a specific environment (e.g., the plants mentioned above among flora, or the common goldfish, *Carassius auratus* among fauna).

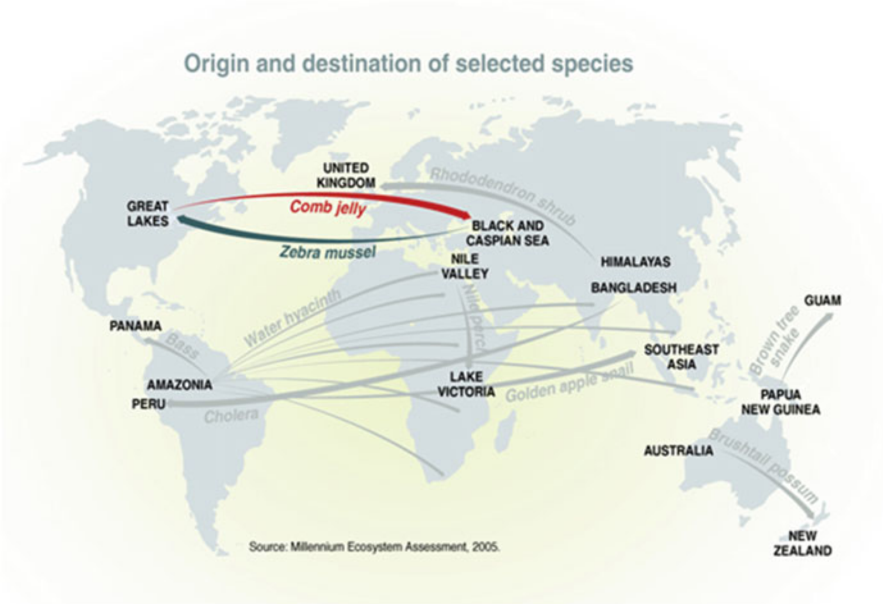

Fig. 10.1 Invasive Species around the World (With permission from Source: Philippe Rekacewicz, UNEP/GRID-Arendal)

To summarize the definition incoherence, it can be said that "the term **invasive** has been used to describe among other things: (1) any introduced non-indigenous species; (2) introduced species that spread rapidly in a new region; (3) introduced species that have harmful environmental impacts, particularly on native species" (Ricciardi and Cohen 2007); and (4) introduced species that have a socio-economic impact (economy, tourism, human health) (EEA 2009).

To accentuate these definitions, a bird species is considered as an alien invasive species under the following conditions: (1) it has been introduced (intentionally or accidentally) to a site previously unknown to it; (2) it becomes proficient to breed without extra human involvement; (3) it spreads and develops as a pest impacting the local biodiversity, environment, the economy, and/or society, as well as human health. Perhaps the best known examples are the European Starling (*Sturnus vulgaris*), Common Myna (*Acridotheres tristis*), and the Red-vented Bulbul (*Pycnonotus cafer*), which are among the "100 of the World's Worst Invasive Alien Species" (a subset of the Global Invasive Species Database) (Anonymous 2014a, b, c). The "Delivering Alien Invasive Species Inventories for Europe" (DAISIE) project selected the Canada goose (*Branta canadensis*), ruddy duck (*Oxyura jamaicensis*), rose-ringed parakeet (*Psittacula krameri*), and sacred ibis (*Threskiornisa ethiopicus*) as among the 100 most invasive species in Europe (Anonymous 2013). In USA, among plants, *Lygodium microphyllum* (generally known as climbing maidenhair fern), a fern originating in tropical Africa, South East Asia, Melanesia, and Australia, became an invasive weed in Florida and

Alabama's open forest and wetland areas (Pemberton 1998; Volin et al. 2004). Here is the place to ask a straightforward question: is every alien species a hazard to its newly invaded environment?

According to DAISIE (Delivering Alien Invasive Species Inventories for Europe, a project supported by the European Commission under the Sixth Framework Program) among the ~11,000 alien species encountered in Europe, the majority are interim innocuous, while ~15 % cause economic damages and ~15 % harm biological diversity (the environment, habitats of animals, plants and microorganisms) (Anonymous 2013; Vilà et al. 2011). Table 10.1 shows several invasive alien species that belong to those ~30 % that are hazardous in a certain geographic area: Florida, USA (Anonymous 2006).

A look at the anti-IAS's organizations and their published material makes it clear that we are increasingly aware of this environmental phenomenon (at the national and international level) and many environmental organizations are involved in IAS problem definition, its state, and response through database organization, real time reports, indicator systems, and response/combat when needed.

However, at present, trying to find a more precise definition of an invasive species, we envision the introduction of flora and fauna that harmfully affect bioregions (economically, environmentally, and ecologically); however, not only these.

10.2 Factors Enhancing/Limiting IAS

Invasive alien species can be divided in two major groups: one that is characterized by mobility and can move freely along a wide range of geographic distribution (even very long distances, in the case of migratory birds), and a second that is characterized by immobility (e.g., plants) and can be transported only by animals/ human activity or air/water currents. The first group is less reliant on human activity but can be affected by it in terms of their invasiveness. The second group is dependent mostly on human global activity, as shown in Table 10.2.

Among the factors that impact IAS distribution can be found: landscape use (deforestation; aquaculture; canals, i.e., Suez); global trade (ships ballasts and fouling); tourism (recreational boats, angling, botanical gardens, parks); aquarium trade] armed conflicts and reconstruction; regulatory regimes; biological control of pests and public health and environmental concerns. All these are orchestrated by humans (Kettunen et al. 2009). The last factor, environmental concerns, includes climate change; perhaps the only one for which human activity cannot be absolutely blamed, regardless of many scientific studies that have shown our central role in climate change fluctuations! A good example of climate change impact has been seen in the present-day Mediterranean marine biodiversity. This marine biodiversity is undergoing a rapid alteration through the increased occurrence of warm-water biota, tagged Mediterranean "tropicalization" (Zenetos et al. 2011). Together with the Atlantic influx, Suez Canal (lessepsian) migration, and humans' introduction of alien species, the Mediterranean Sea harbors an increased tropical

Table 10.1 Some examples of aggressive invasive alien species in Florida

Name	Type	Origin	Extent	Damage	Benefits
Brazilian Pepper (*Schinus terebinthifolius*) 	Shrub	Brazil & Paraguay; introduced in nineteenth century	Central & South Florida 700,000 acres	Shades out other plants, toxic to wildlife, causes poison ivy-like reaction	Ornamental plant; melliferous flower; spices
Cane toad (*Rhinella marina*) 	Amphibian	Amazon basin to the Rio Grande Valley; introduced accidentally in 1955	Spread via canals, found in 21 counties, Florida	Toxic secretions can kill pets or native predators; competes with native amphibians, eat insects	Predators' food including humans; biological pest control; laboratory animals
Chinese tallow (*Triadica sebifera*) 	Tree	China; introduced in eighteenth century	Northern & Central Florida, 38 counties	Displaces native trees; falling leaves contribute to nutrient loading in streams; oily seeds toxic to cattle	Ornamental honey plant for beekeepers; soap production;
Citrus canker (*Xanthomonas axonopodis*) 	Bacterium	Southeastern Asia; first found in USA in 1910	Florida's 11 counties currently quarantined	Highly contagious disease that causes citrus trees to drop their leaves and fruit. 2.9 million trees have been destroyed	

(continued)

Table 10.1 (continued)

Name	Type	Origin	Extent	Damage	Benefits
Cogon grass (*Imperata cylindrica*) 	Grass	Southeast Asia; introduced in 1920s and 1930s for forage and soil stabilization	Roadsides, fields & woods in Central & North Florida	Displaces native plants; little food value for wildlife; creates severe fire hazards	Ornamental; roof thatching; ground cover and soil stabilization; food; paper-making
Hydrilla (*Hydrilla verticillata*) 	Aquatic plant	Africa & Southeast Asia; introduced in Tampa area as an ornamental in 1950s	50,000 acres; 140,000 acres of tubers that could still resprout	Clogs waterways, restricting recreation; kills other aquatic life by blocking sunlight and consuming oxygen; promotes breeding of mosquitos	Bioremediation hyper-accumulator of Mercury, Cadmium, Chromium and Lead, and as such can be used in phytoremediation; high resistance to salinity; ornamental
Melaleuca 	Tree	Australia; introduced 1906 for windbreaks, timber & landscaping	South Florida 400,000 acres	Displaces native plants; alters water flow in everglades; oily leaves promote serious fires	Essential oil with medicinal qualities; drains low-lying swampy areas
Water hyacinth (*Eichhornia crassipes*) 	Aquatic plant	South America; introduced in 1880s	120,000 acres in 1960s, reduced to 2000 acres	Kills fish through anoxia; promotes breeding of mosquito; blocks waterways and crowds out native species	Biomass; wastewater phytoremediation, food and medicine

Adapted from Florida Fish and Wildlife Conservation Commission and Defenders of Wildlife (Anonymous 2014a, b; FLEPPC 2013)

Table 10.2 Factors impacting IAS global spread (FAO 2005)

Factor	Details	Examples	References
Land use changes including forest activities	Deforestation, reforestation, plantation, and timber industry	*Melaleuca quinquenervia* a native tree of Australia introduced into southern Florida (USA) invaded Florida's Everglades National Park; *Prunus serotina* a native tree of North America introduced into Europe, today an aggressive invasive species, mostly in Germany; Re-emergence of infectious diseases (leishmaniasis, yellow fever, trypanosomiasis (both African sleeping sickness and Chagas disease) through increased forest activity and human contact	Porazinska et al. (2007), Dassonville et al. (2008), Doren et al. (2009), Anonymous (2005)
Economics and trade	Globalization, material trade, vehicles (cars and trucks) trains, planes, ships, railways	A major source of forest pests and diseases originate from unprocessed wood, wood products, and nursery stock. For example, in the United States: chestnut blight (*Cryphonectria parasitica*), Dutch elm disease (*Ophiostoma ulmisensulato*), and white pine blister rust (*Cronartium ribicola*)	Bryner et al. (2012), Santini et al. (2005), McKinney et al. (2009), Robinet et al. (2009), Hummel (2003), Meyerson and Mooney (2007) and Vilà et al. (2010)
		The pinewood nematode (*Bursaphelenchus xylophilus*), the pine wilt disease agent spread from its native North America to Asia and Europe in wooden packing materials	
Climate change and changes in atmospheric composition	Human activities releasing greenhouse gases: (CO_2), methane, nitrous oxide, halocarbons, and ozone into the atmosphere. Consequently, the annual temperature rises causing species to spread into higher latitudes and altitudes	Climate warming trends may also allow for longer breeding seasons for invasive species, as observed in populations of the collared dove (*Streptopelia decaocto*) in Europe	Crooks and Soulé (1999) and Sheppard et al. (2014)
Tourism	Travelers can intentionally transport plant and animal species that can turn into invasive, or unintentionally they can transport fruits and other living or preserved plant materials that harbor insects and diseases that can have hazardous effects on agriculture, forestry and other sectors	For instance, Arctic species such as chickweed and yellow bog sedge have been found in Antarctica, able to tolerate low temperatures	Chown et al. (2012) and McNeely et al. (2001)

(continued)

Table 10.2 (continued)

Factor	Details	Examples	References
Conflicts and reconstructions	Wars and military conflicts lead to the collapse of controls and management systems (for plants and animals health), loss of supply lines for materials, the displacement of extensive numbers of people, lack of inspections and border controls increasing the unregulated movement of military personnel and refugees	During World War II, American troops inadvertently introduced the root rot of the pine tree (*Heterobasidio nannosum*) into Italy, causing an unprecedented mortality rate of stone pines (*Pinus pinea*). It is assumed that this pathogen was transferred in transport crates, pallets, or other military equipment made from untreated lumber from infected trees. Foreign food aid has been blamed for introducing agricultural pests into several African countries, such as the larger grain borer (*Prostephanus truncatus*), e.g., into the United Republic of Tanzania in a food aid shipment in 1979	Gonthier et al. (2004), FAO (2001a)
	Displaced people and their belongings can be a dispersal mechanism for, or the source of, alien invasive species		
	Increased smuggling can relocate alien species to new regions		
	Inflows of food aid may be contaminated with pests and diseases		
	Difficulties in obtaining access to border areas because of landmines and other hazards make these areas difficult to survey		
Regulatory regimes	Regulatory systems for managing alien invasive species are strongly dependent on the actions of both the government and private sectors. Its effectiveness is determined by the national resources' level and technical capacity provided by the government	New Zealand Ministry of Primary Industries site, http://www.biosecurity.govt.nz/regs/imports, shows a variety of regulations for controlling IAS introduction in this country. Most developed countries have regulatory systems controlling trade and transport of plants and animals species over international borders	FAO (2001a) and Kettunen et al. (2009)

Biological control of pests	Alternative source of IAS is the intentional importation and release of insects, snails, plant pathogens, and nematodes for pests biological control (biocontrol)	The coccinellid beetle *Harmonia axyridis* has been introduced as a biological control agent in Europe and the USA. Since its introduction, it has established and spread, and is now regarded as an invasive alien species	Raak-van den Berg et al. (2012)
Public health and environmental concerns	Concerns about human health and pesticides/herbicides application (e.g., organic agriculture) may promote the unchecked spread of IAS	*Rhinocyllus conicus*, a seed-feeding weevil, was introduced to North America to control exotic thistles (Musk and Canadian). However, the weevil does not target only the exotic thistles; it also targets native thistles that are essential to various native insects that rely solely on native thistles and do not adapt to other plant species	FAO (2001a) and Rand and Louda (2006)

marine biota (Raitsos et al. 2010; Anonymous 2011b). In connection with waterways, European inland waterways provide new prospects for the spread of nonnative aquatic species or IAS. The introduction pathways of IAS in Europe through aquatic networks have been defined, e.g., shipping (passage of ships or port), canals (within river basin or else), wild fisheries (commercial fishery exists in the area-stock movements, population reestablishment, releases of organisms intended as living fish food supplements, movement of fishing equipment), culture activities (aquaculture), ornamental and live food trade (garden centers, ornamental ponds, public aquaria or live food trade), leisure activity (marina or leisure craft visit with festivals; sporting events -including angling-SCUBA diving), alteration to natural water flow (hydrotechnical activities: creation of reservoirs, dams, dredging activities), thermal pollution (discharges of heated waters from power plants, untreated wastewater discharges), research and education (research activities with alien organisms or demonstration cultures of alien organisms), biological control (known biological control activities), and others (organic and chemical pollution, habitat modification, discharged live packing material, etc.) (Panov et al. 2009; Ojaveer et al. 2014).

An examination of the factors affecting IAS global spread shows that the effectiveness of IAS prevention is debatable (as our world is not a sterile environment), although well-established national and international regulations can reduce IAS spread and its consequences (Table 10.2).

10.3 An Issue of Global Concern

Aichi Target 9 states that "by 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment"; Target 5 of the EU Biodiversity Strategy (EC 2011) is similar.

The EU Biodiversity Strategy (EC 2011) specifically stresses the need to assess pathways of biological invasions through its Target 5: "By 2020, invasive alien species and their pathways are identified and prioritized, priority species are controlled or eradicated, and pathways are managed to prevent the introduction and establishment of new invasive alien species."

Recognizing the need for a comprehensive instrument at EU level to tackle biological invasions effectively, the European Commission has recently issued a Communication presenting policy options for an EU Strategy on Invasive Species (EC 2008a). Furthermore, the Marine Strategy Framework Directive (MSFD; EC 2008b), which is the environmental pillar of EU Integrated Maritime Policy, sets as an overall objective to reach or maintain "Good Environmental Status" (GES) in European marine waters by 2020. It specifically recognizes the introduction of marine alien species as a major threat to European biodiversity and ecosystem health, requiring member States to include alien species in the definition of GES and the setting of environmental targets to reach it. Hence, one of the 11 qualitative descriptors of GES defined in the MSFD is that "non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystem" (Descriptor 2).

Currently a dedicated legislative instrument is being developed by the Commission as dictated by Action 16 of the Biodiversity Strategy. Among the indicators adopted to assess this descriptor are "trends in abundance, temporal occurrence and spatial distribution in the wild of non-indigenous species, particularly invasive non-indigenous species, notably in risk areas, in relation to the main vectors and pathways of spreading of such species" (Cardoso et al. 2010).

The SEBI (Streamlining European Biodiversity Indicators) 2010 process was established "to streamline national, regional and global indicators and, crucially, to develop a simple and workable set of indicators to measure progress and help reach the 2010 target" (EEA 2012). The SEBI process was initiated by generating >140 possible biodiversity indicators, a number that was later reduced to 26 through rigorous criteria by 2007 (Table 10.3).

In 2005, based on the report titled "Invasive alien species indicators in Europe, a review of streamlining European biodiversity (SEBI) Indicator 10," three indicators or "elements of an indicator" were submitted to the SEBI coordination team (EEA 2012):

1. Cumulative numbers of alien species in Europe since 1900;
2. Selected worst IAS threatening biodiversity in Europe;
3. Selected impacts/abundance of IAS;

Table 10.3 SEBI[a] 2010 indicators within CBD[b] focal areas and EU headline indicators

CBD focal area	Headline Indicator	SEBI 2010 specific indicator
Status and trends of the components of biological diversity	Trends in the abundance and distribution of selected species	1. Abundance and distribution of selected species
		(a). Birds
		(b). Butterflies
	Change in status of threatened and/or protected species	2. Red list Index for European species
		3. Species of Europe interest
	Trends in extent of selected biomes, ecosystems, and habitats	4. Ecosystem coverage
		5. Habitats of European interest
	Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socioeconomic importance	6. Livestock genetic diversity
	Coverage of protected areas	7. Nationally designated protected areas
		8. Sites designated under the EU Habitats and Birds Directives
Threats to biodiversity	Nitrogen deposition	9. Critical load exceedance for nitrogen
	Trends in invasive alien species (numbers and costs of invasive alien species)	10. Invasive alien species in Europe
	Impact of climate change on biodiversity	11. Impact of climatic change on bird population

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Table 10.3 (continued)

CBD focal area	Headline Indicator	SEBI 2010 specific indicator
Ecosystem integrity and ecosystem goods and services	Marine Trophic Index	12. Marine trophic
	Connectivity/fragmentation of ecosystems	13. Fragmentation of natural and semi-natural areas
		14. Fragmentation of river systems
	Water quality in aquatic ecosystems	15. Nutrients in transitional, coastal and marine waters
		16. Freshwater quality
Sustainable use	Area of forest, agricultural, fishery and aquaculture ecosystems under sustainable management	17. Forest: growing stock, increment and fellings
		18. Forest: deadwood
		19. Agriculture: nitrogen balance
		20. Agriculture: area under management practices potentially supporting biodiversity
		21. Fisheries: European commercial fish stocks
		22. Aquaculture: effluent water quality from finfish farms
	Ecological Footprint of European countries	23. Ecological footprint of European countries
Status of access and benefits sharing	Percentage of European patent applications for inventions based on genetic resources	24. Patent applications based on genetic resources
Status of resources transfers	Funding to biodiversity	25. Financing biodiversity management
Public opinion (additional EU focal area)	Public awareness and participation	26. Public awareness

[a]SEBI = Streamlining European Biodiversity Indicators
[b]CBD = Convention on Biological Diversity

4. Awareness of IAS;
5. Cost of IAS.

Among the above three suggested indicators, only two were selected: (1) "cumulative numbers of alien species in Europe (since 1900)," and (2) "selected worst IAS threatening biodiversity in Europe"; the other three were rejected on the basis of weaknesses and uncertainty. From the database collection for the years since 1900 and its analysis, it was found that the suggested indicator No. 1, based on the cumulative decadal database and geographical spread, clearly shows that there is a steady increase in the numbers of alien species in Europe (Figs. 10.2 and 10.3). However, two weaknesses of this indicator were recognized: "a) invasive alien species are not distinguished and b) there is limited geographical coverage for the

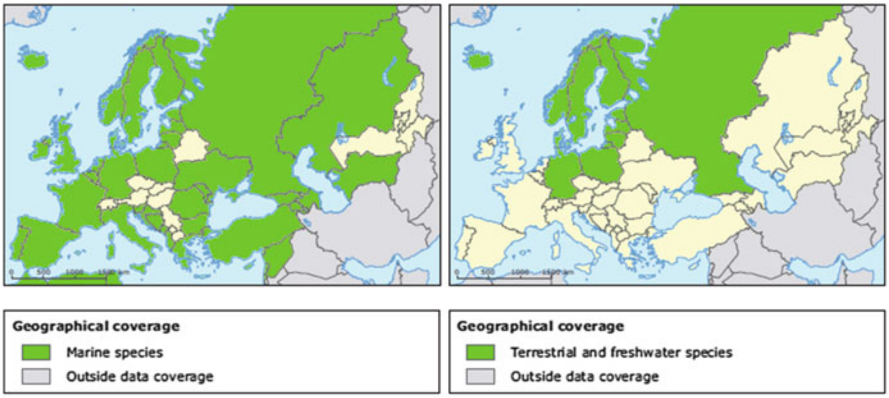

Fig. 10.2 Geographical coverage of the "Cumulative number of alien species established in Europe since 1900" (With permission from EEA 2012)

terrestrial and freshwater data set" (EEA 2012). The second indicator (selected the worst IAS threatening biodiversity in Europe) produced a large database; however, it failed to answer the posed key policy question: which IAS should be targeted by management actions? This indicator has two main recognized weaknesses: a) subjectivity in selection of species, and b) limited measurement of precise impacts of IAS (Fig. 10.4). In spite of its serious limitations ("the main conclusion drawn from the map was that fairly high numbers of listed species can be found in all European countries"), it served well for raising public awareness (EC 2012).

10.4 Justification for Indicator Selection and Potential Indicators

The policy questions such as "is the number of alien species in Europe increasing?" and "which invasive alien species should be targeted by management actions?" were answered using two indicators, which were the "cumulative number of alien species established in freshwater, terrestrial and marine environments," and the "worst invasive alien species threatening biodiversity in Europe." As the 2010 biodiversity target was not met, new global and European targets have to be determined.

In order to confront this relatively new threat successfully, it should be clear that the most hazardous IAS members are those that threaten the biological diversity and habitat destruction. Those species are fast multiplying, growing, and spreading, and thus, altering the eco-habitat and everything encompassed in such a system (Hulme 2007). One of the main indicators of an ecosystem's health is its biodiversity parameter, which may be hampered by IAS, e.g., the sea squirt *Didemnum vexillum* that may cover many square kilometers of sea floor while overgrowing

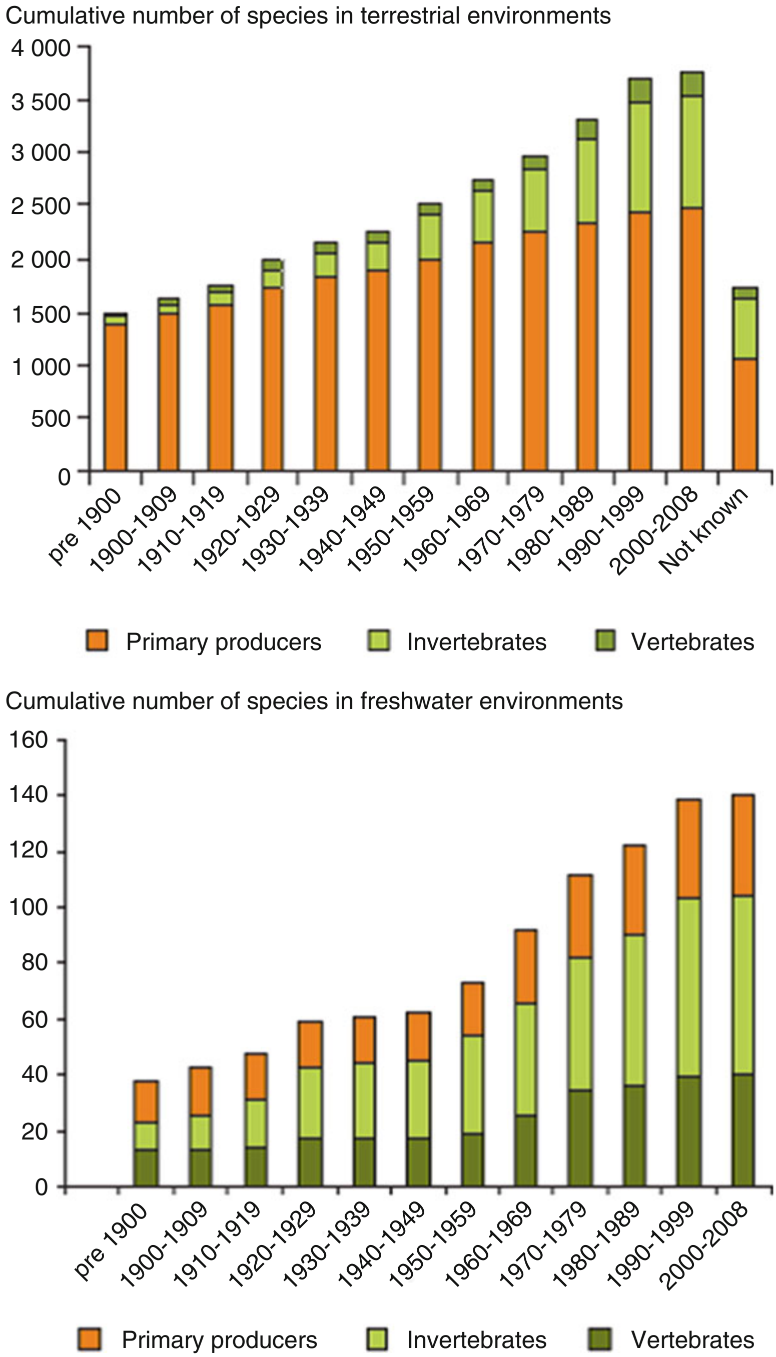

Fig. 10.3 Cumulative numbers of established alien species in Europe (since 1900) (With permission from EEA 2012). **Note:** The geographic coverage for data from the terrestrial and freshwater environments is: Denmark, Estonia, Finland, Germany, Iceland, Latvia, Lithuania, Norway, Poland, Russia and Sweden (With permission from EEA 2012)

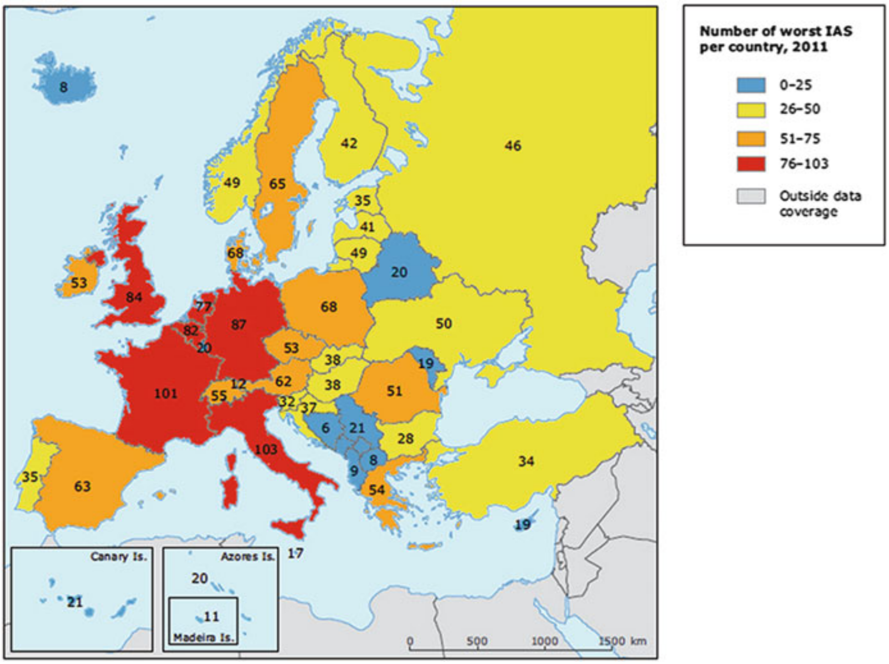

Fig. 10.4 Number of the worst IAS per country and an approximate estimate of their density. **Note:** A few of the worst IAS and some countries are not included in DAISIE, and country distributions are known to be incomplete for several species (With permission from DAISIE, queried November 2011, EEA-SEBI 2012)

other species. This bottom colonizing tunicate can expand over sand, gravel, and cobble, and is capable of growing over other organisms in order to expand (according to its morphology it was also named "marine vomit"!).

Nevertheless, some indicators have been suggested for IAS based on the pressure-state-response model (McGeoch et al. 2010). These indicators are intended to monitor: (1) the size or extent of the threat posed by IAS (pressure), (2) the impact of IAS on biodiversity (state), and (3) the progress towards reducing the threat (via policy or management interventions) (response) (Table 10.4). The following indicators have been selected: number of IAS/country, red list index for impacts of IAS, and international and national policy adoption. It is clear that first we should know "who is who" and, due to the extensive numbers of species, the database should be collected by country on plants, animals, and if possible smaller organisms. Then, a red list of IAS that are harmful to our environment (according to our principles!) should be built in order to warn the national network and also receive field information for database construction. Finally, action should be taken accordingly at the national and international levels (Fig. 10.5).

At a SEBI 2020 meeting held in Copenhagen in 2011, the following indicators were discussed

Table 10.4 Pressure-state-response (model) of invasive alien species (IAS) indicators (McGeoch et al. 2010)

Model parameters	Indicator	Details	References
Pressure	Number of IAS/country	Species impacting biodiversity negatively	Hulme (2009)
		IAS taxa: mammals, birds, amphibians, plants, freshwater fish, marine organisms (algae, corals, invertebrates and fish)	Ricciardi (2001), Cronk and Fuller (1995), Havird et al. (2013), Lonsdale (1999) and Winfield et al. (2011)
		Prospective trends therein at national, regional and global scale	EEA (2009), Stoett (2009), UNEP (2002a,b) and Rabitsch et al. (2013)
State	Red List Index for impacts of IAS	Trends in extinction risk driven by IAS to different taxa	Butchart et al. (2005, 2007)
		Taxa impacted: Birds, mammals, amphibians	Bird Life International (2008), Rodriguez-Cabal et al. (2009) and Anonymous (2009)
Response	International and national policy adoption	Agreements, legislation and policy relevant to reducing IAS threats to biodiversity	Shine et al. (2005, 2009) and Levin and D'Antonio (1999)
		Trends in number thereof and adoption by countries	Vilá et al. (2009)

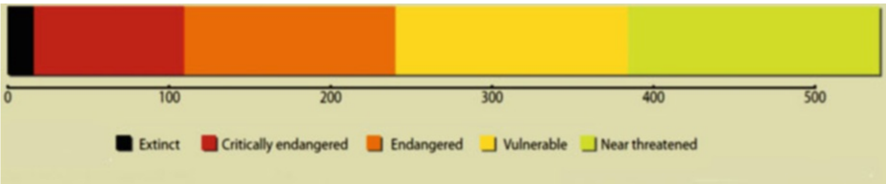

Fig. 10.5 Number of species in International Union for Conservation of Nature (IUCN) Red List categories from Mediterranean countries. Note: included Amphibians, Birds, Cartilaginous fishes, Crabs and Crayfish, Endemic freshwater fishes, Mammals, Dragonflies and Reptiles (Source: IUCN, *The Mediterranean*, a Biodiversity Hotspot Under Threat 2008)

1. Red list index and IAS: The red list index shows trend of red list status changes over time due to IAS. It was done globally, but could be done at the European level as well. It is probably more sensitive for detecting changes as the cumulative number of AS. In addition, the percentage of species impacted based on red list criteria may be useful, as well as the number of protected species threatened by IAS. Ideally, we have an indicator showing a positive trend due, e.g., to management actions.
2. Trends in management pathways: Analyses of management actions vs pathways and numbers of species over time may help prioritize pathways. This can be done for all IAS or for a selected list of species and for different environments. There were two different views about primary and secondary pathways: One is

that primary and secondary introduction pathways should be separated; the other that primary pathways across the biogeographical barrier should be focused on only because secondary pathways are out of our control.

3. Impact indicator: An indicator on impact is needed, although impact is hard to define or standardize, e.g., the red list index, or the impact in habitats of European interest (links to directives), impact on ecosystem services, and impact on economy or socio-economy. There is a need for an indicator for the impact on socio-economy, a work to be done by economists.

   In addition, impact on ecosystem services (ES) may be developed over time by using EASIN and the Vilá et al. (2010) article. Constraints for quantifying and mapping the impact of marine alien species include (1) the lack of coverage and resolution in the available natural and socio-economic data (e.g. habitat mapping, spatial distribution of native and alien species), (2) the gaps for assessing marine ecosystem services (Katsanevakis et al. 2014)
4. ES-s are also included as targets in the EU vision 2050. It should be checked whether the Economics of Ecosystems and Biodiversity (TEEB)-framework can be applied to alien species and assessment of services. Although it seems difficult, at least some of the ES can be identified and linked to IAS in a long term approach.

Newly introduced species indicator can eventually be done by a map showing number of first records per country. Such a map can also be produced for different time periods as trend over time; this would support prevention and rapid response. Nunes et al. (2014) have investigated the gateways of initial introductions of marine alien species in the European Seas. Marked geographic patterns depending on the pathway of introduction were revealed, with specific countries acting as gateways to alien invasions. For example France and Italy were the countries mostly responsible for introductions by aquaculture.

Based on DAISIE data and others, the UNEP-WCMC (2011) suggested four tentative IAS indicators tailored to Aichi Target 9* that relate to ecosystem services: (1) dollar value impact of IAS on crops (pests/disease/pollinators) or % yield; (2) fish and wildlife production; (3) dollar value of impacts of IAS on water availability and (4) daily impacts of IAS on human health (Table 10.5). These indicators are mainly linked to ecosystem-economy and as such are less precise when dealing with systems at higher resolution (Deudero et al. 2011).

More accurate indicators related to operability, relation and policy questions, and indicators are as follows. Hotspot indicators (IAS that are concentrated on specific spots, such as islands), which describe different alien arthropods to be used as indicators of invasion (see Fig. 10.6). Single group indicators that are centred on specific IAS groups, such as invasive alien bird index (based on the Birds Directive) or an invasive alien fish index (based on the WFD) (Brochier et al. 2010). A single species indicator is an excellent alarm system of a specific IAS but less, if at all, effective as a trend indicator (only if it is ecologically connected to more single species indicators) (Ghahramanzadeh et al. 2013). Alien species and climate change: according to most models, IAS will continue to spread, since their opportunism and generalistic character (as species) are able to outperform native species under climate and environmental changes. The amount, colonization, or sweep of

Table 10.5 Potential "new" IAS indicators as related to their operability, relation to policy questions and to operational indicators

Indicator[a]	Operability	Policy questions	Operational indicators
IAS and ecosystem Services	B-C	P	Trends in the economic impacts of selected IAS
Biopollution indexes	B-C	P	Trends in number of IAS
Hotspot indicator	B-C	P,R	Trends in number of IAS; Trends in IAS pathways management
Single group indicator	C	P	Trends in number of IAS
Single species indicator	n/a	R	Trends in number of IAS
Alien species and climate change	C	P	Trends in number of IAS
Animal and plant health	B	P,R	Trends in incidence of wildlife diseases caused by IAS; Trends in IAS pathways management
Important alien areas	C	P	Trends in number of IAS

Operability: A = Priority and ready to use; B = Priority to be developed; C = For consideration; n/a = not applicable

Policy questions: P = Pressure; R = Response

[a]All indicators relate to Aichi Target 9. (See 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 COP 10) which took place in Nagoya, Aichi Prefecture, Japan, in October 2010)

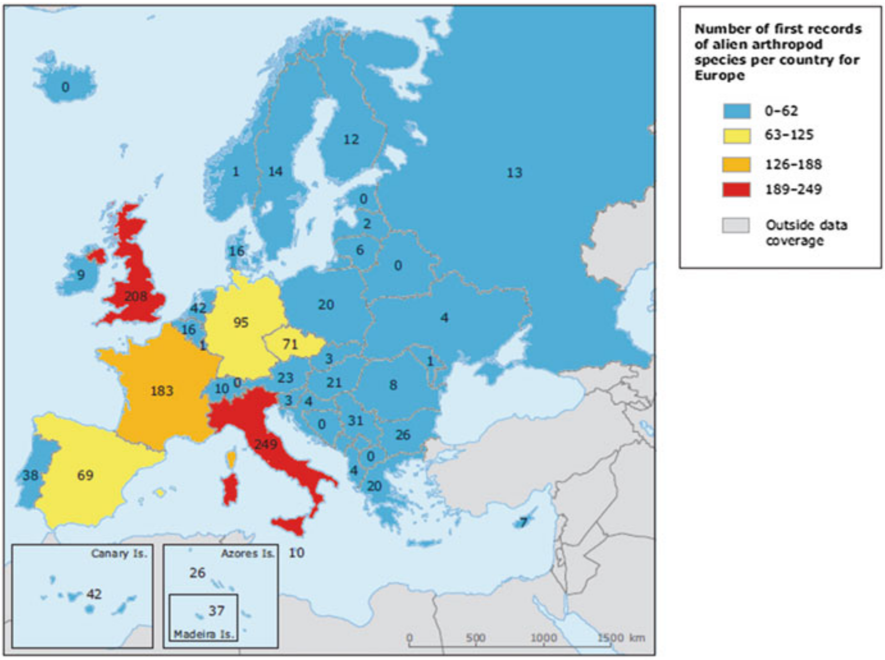

Fig. 10.6 Alien arthropod species per country for Europe (number of first records) (With permission from Roques 2010)

IAS whose presence is approximately related to temperature (e.g., palms, cacti, parakeets or the red-eared slider) may function well as "surrogate indicators" in this category. Nevertheless, in general these IAS patterns are driven by compound factors and rarely based on "clean" climate change phenomena (e.g., extreme cold or draughts) and rarely observed as such; Animal and plant health: according to Aichi Target 9, an indicator on "Trends in incidence of wildlife diseases caused by invasive alien species" should be developed. At the moment such an indicator is not available; nonetheless it may be developed using current data reported to the Animal Disease Notification System (ADNS). ADNS is a notification system to ensure rapid exchange of information between national authorities responsible for animal health. This system is based on a certain list of animal diseases (Annex I of Directive 82/894/EC) (EC 2012) without automatic update of the list for new or emerging diseases. Contained by the Animal Health Strategy, there are several supportive instruments such as TRACES "(a unified database including information on all veterinary matters), improved border biosecurity (revision of import legislation and risk management) and surveillance (including training support)" (EC 2012). In the plant health sector, a similar project has been established with regular updates being carried out. In summary, wildlife diseases' indicators are of high priority (based on present data and strict methodology to be developed). Important alien areas for example relate to IBAs (Important Bird Areas) that describe important bird sites at the national level, those of including IAS. Following a continuous observation regime, the accumulated data can be used as an indicator of IAS impact at a regional scale within protected areas, e.g., national parks. A similar approach has been taken by EC with plants (IPAs-Important Plant Areas) and is hoped that useful data will be collected to define IAS spread and impact. Applying the concept of "Important Alien Areas," the monitoring and measurement of IAS can be successful, especially when import hubs, such as airports or harbor and ecosystems (i.e., lagoons, gardens and parks in cities, forest plantations and national parks), are selected as "hot spots" rich in alien species. When talking about import hubs, the New Zealand example is one of the best: New Zealand has shown stabilization in IAS increase vs. Europe since its strict biosecurity measures were enforced! (Fig. 10.7).

10.4.1 Raising Public Awareness – Involvement of Citizen Scientists

Institutes often lack funds and manpower to perform large-scale biodiversity monitoring. Citizens can be involved, contributing to the collection of data, thus decreasing costs. Citizen Science has become to contribute to the wealth of information about alien species. Terrestrial and Aquatic resource managers have taken advantage of volunteer networks such as the Invasive Plant Atlas of New England IPANE (Simpson et al. 2009). Volunteers are trained to look for new incursions of both known and anticipated alien invaders, and to gather and submit basic ecological information on invasive plants that encounter on the New England

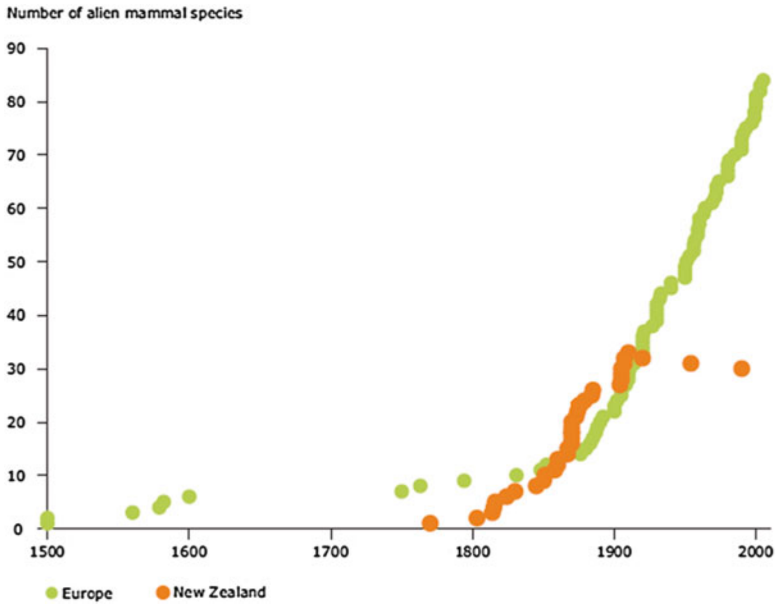

Fig. 10.7 Comparison of the number of alien mammals' species in Europe and New Zealand (1500–2000 BC). Note: New Zealand shows stabilization in IAS increase vs. Europe since its strict biosecurity measures had been enforced! (With permission from P. Genovesi, unpublished data, from http://www.eea.europa.eu/legal/copyright)

landscape via the IPANE Web site (http://www.ipane.org). Considerable citizen science support on alien species is also provided by ornithologists (Delaney et al. 2008); divers (Zenetos et al. 2013).

10.5 Case Studies: Indicators Based on IAS

10.5.1 Indicator: Trends in IAS

Selecting the "most" invasive species is a difficult task which can attract debate During the SEBI 2010 exercise, trends in alien species was used as a proxy to Trends in IAS. Approximately 1,400 alien species have been introduced in European Seas, 1,200 of them since 1950. The vast majority are invertebrates (mostly crustaceans and molluscs), followed by plants and vertebrates (mostly fish) (Fig. 10.8-left). The rate of introductions is continually increasing, with almost 300 new species reported since 2000. The introduction rate is relatively high in the North Sea, the Bay of Biscay and Iberian shelf, Celtic Seas, while the lowest is the contribution of new aliens in the Baltic Sea. This does not imply that the Baltic is less impacted.

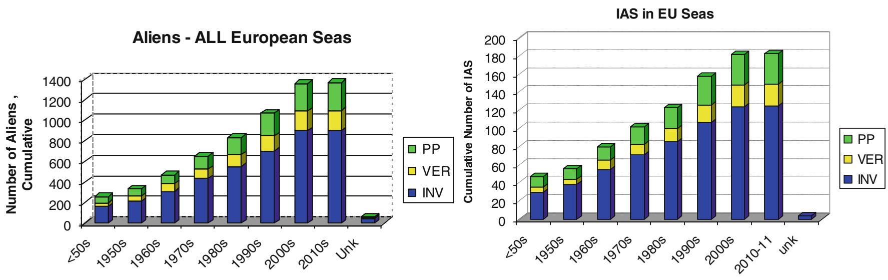

Fig. 10.8 Cumulative number of aliens in the European Seas by 2013. *left*: all aliens; *right* invasive species only (Data source: HCMR/EEA database)

Similarly, the high number of alien species in the Mediterranean does not imply higher overall impact, because many of them are harmless, while a number of them (fish, crabs, and shrimps) are commercially exploited.

Here we take a step toward presenting the trends in marine IAS in European Seas as compared to the trends of all introduced species. A list of target species was compiled by combining and updating the '100 of The Worst' list of DAISIE (Delivering Alien Invasive Species Inventories for Europe; http://www.europe-aliens.org/speciesTheWorst.do), the NOBANIS fact sheets on Invasive Alien Species (European Network on Invasive Alien Species; http://www.nobanis.org/Factsheets.asp), the SEBI 'List of worst invasive alien species threatening biodiversity in Europe' (Streamlining European 2010 Biodiversity Indicators; http://biodiversity.europa.eu/topics/sebi-indicators), and the datasheets of CABI's Invasive Species Compendium (CABI-ISC; http://www.cabi.org/isc/).

10.5.2 *Indicator: Species per Country*

Based on a thorough review of the scientific and grey literature, the country and year of initial introduction of marine alien species in Europe by February 2014 was identified (for approximately 1,400 species). The country through which a species was first introduced in Europe will hereafter be called 'recipient country.' For 31 species, more than one recipient country was associated with their introduction into European Seas. This may happen when a species data have been collected independently in the same year from different countries. In some cases, recipient countries can be identified with certainty (e.g., most commodity species introduced through aquaculture), while in other cases the country of first observation of the species in Europe was assumed to be the recipient country. The date of first observation of an alien species in Europe was used as the best available estimate of the year of its initial introduction, when the latter could not be determined with certainty. The information on the country and year of first introduction of each species is publicly available through the species search widgets of EASIN (http://

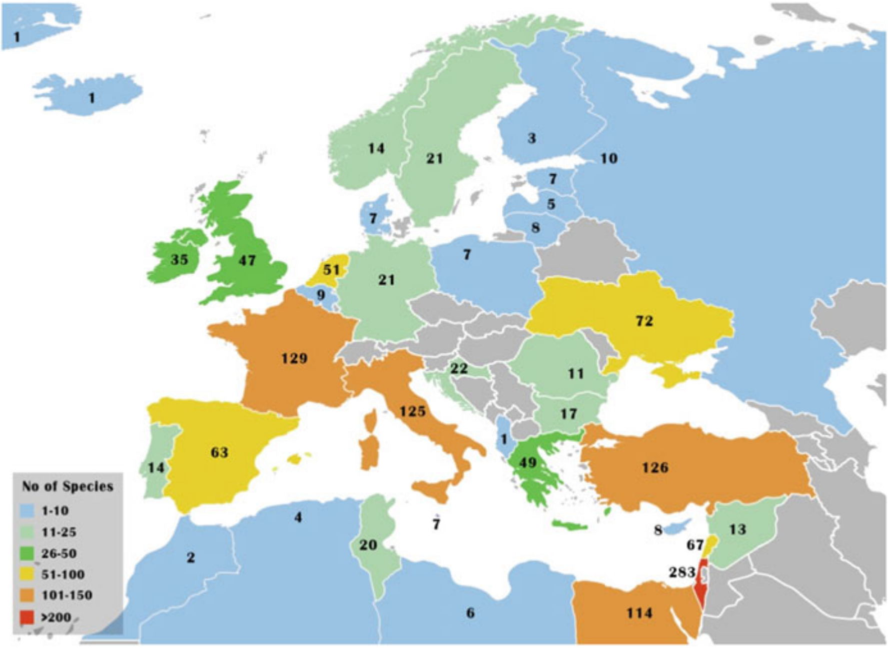

Fig. 10.9 Number of marine/estuarine alien species introduced for the first time in European waters through different pathways of introduction, per recipient country (i.e. countries of initial introduction in Europe) (Source: HCMR/EEA database)

easin.jrc.ec.europa.eu/use-easin/species-search). Figure 10.9 illustrates the number of aliens first recorded per recipient country.

Israel is the country with the highest number of recorded first introductions in European Seas, followed by Turkey, France, Italy, and Egypt (Fig. 10.9). The number of new invaders in Israel, Egypt, and Turkey is justified by their vicinity to the Suez Canal (Lessepsian immigrants), whereas Italy and France first host many invaders presumably due to extensive aquaculture activities.

10.5.3 Indicator: Trends in Pathways/Vectors

Assessing pathways of introduction of marine alien species is essential for identifying management options and evaluating management decisions to regulate and prevent new introductions. On reviewing critically related information in scientific/grey literature and online resources, 1,360 alien marine species in European seas were identified by 2012, of which 1,269 were linked to the most probable pathway(s)/vector(s) of primary introduction. Aquaculture was the only pathway for which there was a marked decrease in new introductions during the last decade, presumably due to compulsory measures implemented at a national or European level.

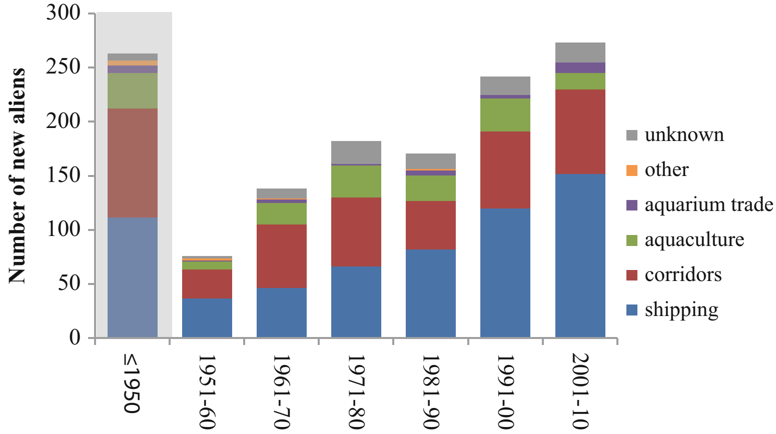

Fig. 10.10 Temporal trends in the numbers of new recorded marine aliens in Europe in relation to the pathways of introduction (Source: Katsanevakis et al. 2013)

Introductions via all the other pathways have been increasing, aquarium trade being the pathway with the most striking observed increase (Fig. 10.10). Many more species are expected to invade the Mediterranean Sea through the Suez Canal, as it has been continuously enlarged and the barriers to the invasion of Indo-Pacific Sea species have been substantially decreased. It has been estimated that approximately a new species is introduced in the Mediterranean every two weeks (Zenetos et al. 2012). Whereas lessepsian migration cannot be managed, in addition to the existing regulations on aquaculture, the implementation of appropriate management measures on shipping and aquarium trade could reverse the increasing trend in new introductions.

10.6 Summary

At present, the IAS indicators situation still needs improvement based on new databases and broader geographical areas. For example, the European Commission on IAS recommended increasing the cumulative numbers of alien species in their geographical area to 1500–1800 species to be included in the list to be covered scientifically. Prioritizing IAS is included in the new EU Regulation. Interestingly, the EC agreed to continue to cover the costs of IAS in Europe (the economic indicators) to be used further in combination with other indicators. The central recommendations have been the development of new indicators and elaboration of the two novel indicators already proposed: (a) the red list Index and (b) the combined index of invasion trends. Furthermore, quantification and mapping of impacts will assist stakeholders in their decisions for prevention or mitigation actions. Engaging citizen scientists to survey local biota detect and report new incursions of both known and anticipated alien is expected to result in the collection of significant data sets, which could potentially be used for an early-warning system *inter alia*.

References

Anonymous (2005) Restoration Coordination and Verification (RECOVER). 2005. The RECOVER team's recommendations for interim goals and interim targets for the Comprehensive Everglades Restoration Plan: Final Report, 10 Jan 2005

Anonymous (2006) South Florida ecosystem restoration "exotic plant indicator" development of an invasive exotic plant metric, Science Coordination Group (SCG) & Restoration Coordination and Verification (RECOVER), pp 1–21

Anonymous (2009) Birds Directive (Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds)

Anonymous (2011a) Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions Towards an EU Strategy on Invasive Species (PDF). Retrieved 17 May 2011

Anonymous (2011b) University of Gothenburg, "Mediterranean Sea invaded by hundreds of alien species." ScienceDaily. ScienceDaily, 24 May 2011. www.sciencedaily.com/releases/2011/05/110523171111.htm

Anonymous (2013) DAISIE European invasive alien species gateway. http://www.europe-aliens.org/

Anonymous (2014a) Global invasive species database. http://www.issg.org/database

Anonymous (2014b) Defenders of Wildlife, 1130 17th Street NW, Washington, DC 20036. www.defenders.org/publication/invasive-species-florida

Anonymous (2014c) Florida Fish and Wildlife Conservation Commission http://myfwc.com/

Bird Life International (2008) State of the world's birds 2008: indicators for our changing world. Bird Life International, Cambridge

Brochier B, Vangeluwe D, van den Berg T (2010) Alien invasive birds. Rev Sci Tech 29(2):217–225

Bryner SF, Rigling D, Brunner PC (2012) Invasion history and demographic pattern of *Cryphonectria hypovirus* 1 across European populations of the chestnut blight fungus. Ecol Evol 2(12):3227–3241

Butchart SHM, Stattersfield AJ, Bennun LA, Akçakaya HR (2005) Using Red List Indices to measure progress towards the 2010 target and beyond. Philos Transcr R Soc 1454:255–268

Butchart SHM, Akçakaya HR, Chanson J, Baillie JEM et al (2007) Improvements to the Red List Index. PLoS One 2:e140. doi:10.1371/journal.pone.0000140

Cardoso AC, Cochrane S, Doerner H, Ferreira JG et al (2010) Scientific support to the European Commission on the marine strategy framework directive: management group report, JRC scientific and technical reports. Office for Official Publications of the European Communities, Luxembourg, 57 pp

Chown SL, Huiskes AHL, Gremmen NJM, Lee JE et al (2012) Continent-wide risk assessment for the establishment of non indigenous species in Antarctica. Proc Natl Acad Sci U S A 109(13):4938–4943

Cronk QBC, Fuller JL (1995) Plant Invaders: the threat to natural systems. Chapman & Hall, London, 241

Crooks KR, Soulé ME (1999) Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400:563–566

Dassonville N, Vanderhoeven S, Vanparys V, Hayez M et al (2008) Impacts of alien invasive plants on soil nutrients are correlated with initial site conditions in NW Europe. Oecologia 157(1):131–140

Delaney DG, Sperling CD, Adams CS, Leung B (2008) Marine invasive species: validation of citizen science and implications for national monitoring networks. Biol Invasions 10(1):117–128

Deudero S, Box A, Alos J, Arroyo NL et al (2011) Functional changes due to invasive species – food web shifts at shallow *Posidonia oceanica* seagrass beds colonized by the alien macroalga Caulerpa racemosa. Estuar Coast Shelf Sci 93(2):106–116

Doren RF, Trexler JC, Gottlieb AD, Harwell MC (2009) Ecological indicators for system-wide assessment of the greater everglades ecosystem restoration program. Ecol Indic 9(6):s2–s16

EC (2008a) Towards an EU strategy on invasive species. COM/2008/789. European Commission, Brussels, 10 pp

EC (2008b) Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008, establishing a framework for community action in the field of marine environmental policy (Marine strategy framework directive). Off J Eur Union L164:19–40

EC (2011) Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM/2011/244. European Commission, Brussels, 16 pp

EC (2012) Technical report No 15/2012 Invasive alien species indicators in Europe. A review of streamlining European biodiversity (SEBI) Indicator 10. ISSN 1725-2237. European Environment Agency (EEA), p 46

EEA (2009) Progress towards the European 2010 biodiversity target, EEA report no 4/2009, European Environment Agency. http://www.eea.europa eu/highlights/publications/progress-towards-the-european-2010-biodiversity-target/

FAO (2001a) Global forest resources assessment 2000: main report, FAO forestry paper 140. FAO, Rome

FLEPPC (2013) List of invasive plant species. Florida Exotic Pest Plant Council. Internet: http://www.fleppc.org/list/11list.htm or Wildland Weeds Vol 14(3–4):11–14. Summer/Fall 2011

Food and Agriculture Organization (FAO) (2005) The state of the world's forests 2005. Rome. Available at www.fao.org/docrep/007/y5574e/y5574e00.htm

Genovesi P, Butchart SHM, McGeoch MA, Roy DB (2012) Monitoring trends in biological invasions, its impact and policy responses. In: Collen B et al (eds) Biodiversity monitoring & conservation: bridging the gap between global commitment and local action. Wiley-Blackwell, Cambridge

Ghahramanzadeh R, Esselink G, Kodde LP, Duistermaat H et al (2013) Efficient distinction of invasive aquatic plant species from non-invasive related species using DNA barcoding. Mol Ecol Res 13(1):21–31

Gonthier P, Warner R, Nicolotti G, Mazzaglia A et al (2004) Pathogen introduction as a collateral effect of military activity. Mycol Res 108:468–470

Havird JC, Weeks JR, Hau S, Santos SR (2013) Invasive fishes in the Hawaiian anchialine ecosystem: investigating potential predator avoidance by endemic organisms. Hydrobiologia 716(1):189–201

Hulme PE (2007) Biological invasions in Europe: drivers, pressures, states, impacts and responses. In: Hester R, Harrison RM (eds) Biodiversity under threat, vol 25, Issues in environmental science and technology. Royal Society of Chemistry, Cambridge, pp 56–80

Hulme PE (2009) Trade, transport and trouble: managing invasive species pathways in an era of globalization. J Appl Ecol 46:10–18

Hummel HE (2003) Introduction of *Diabrotica virgifera virgifera* into the Old World and its consequences: a recently acquired invasive alien pest species on Zea mays from North America. Commun Agric Appl Biol Sci 68(4 Pt A):45–57

Katsanevakis S, Zenetos A, Belchior C, Cardoso AC (2013) Invading European seas: assessing pathways of introduction of marine aliens. Ocean Coast Manag 76:64–74

Katsanevakis S,Wallentinus I, Zenetos A, Leppakoski E et al (2014) Impacts of marine invasive alien species on ecosystem services and biodiversity: a pan-European critical review. Aquat Invasions 9(4) (in press). doi:http://dx.doi.org/10.3391/ai.2014.9.4.01

Kelly DJ, Hawes I (2005) Effects of invasive macrophytes on littoral-zone productivity and foodweb dynamics in a New Zealand high-country lake. J N Am Benthol Soc 24(2):300–320

Kettunen M, Genovesi P, Gollasch S, Pagad S et al (2009) Technical support to EU strategy on invasive species (IAS) — Assessment of the impacts of IAS in Europe and the EU, Final report for the European Commission, Institute for European Environmental Policy (IEEP), Brussels, Belgium, 44 p

Levin JM, D'Antonio CM (1999) Elton revisited: a review of the evidence linking diversity and invasibility. Oikos 87:15–26

Lonsdale WM (1999) Global patterns of plant invasions and the concept of invasibility. Ecology 80:1522–1536

McGeoch MA, Butchart SHM, Spear D, Marais E (2010) Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. Divers Distrib 16:95–108

McNeely JA, Mooney HA, Neville LE, Schei P, Waage JK (2001) Global strategy on invasive alien species. IUCN, Gland/Cambridge

McKinney ST, Fiedler CE, Tomback DF (2009) Invasive pathogen threatens bird-pine mutualism: implications for sustaining a high-elevation ecosystem. Ecol Appl 19(3):597–607

Meyerson LA, Mooney HA (2007) Invasive alien species in an era of globalization. Front Ecol Environ 5(4):199–208

Nunes AL, Katsanevakis S, Zenetos A, Cardoso AC (2014) Gateways to alien invasions in the European seas. Aquat Invasions 9(2):133–144

Ojaveer H, Galil BS, Minchin D, Olenin S et al (2014) Ten recommendations for advancing the assessment and management of non-indigenous species in marine ecosystems. Mar Policy 44:160–165

Panov VE, Alexandrov B, Arbačiauskas K, Binimelis R et al (2009) Assessing the risks of aquatic species invasions via European inland waterways: from concepts to environmental indicators. Integr Environ Assess Manag 5(1):110–126

Pemberton RW (1998) The potential of biological control to manage old world climbing fern (*Lygodium microphyllum*), an invasive weed in Florida. Am Fern J88(4):176–182

Porazinska DL, Pratt PD, Glblin-Davis RM (2007) Consequences of *Melaleuca quinquenervia* invasion on soil nematodes in the Florida Everglades. J Nematol 39(4):305–312

Raak-van den Berg CL, De Lange HJ, Van Lenteren JC (2012) Intraguild predation behavior of ladybirds in semi-field experiments explains invasion success of Harmonia axyridis. PLoS One 7(7):e40681

Rabitsch W, Milasowszky N, NehringS WC et al (2013) The times are changing: temporal shifts in patterns of fish invasions in central European fresh waters. J Fish Biol 82:17–33

Raitsos D, Beaugrand G, Georgopoulos D, Zenetos A et al (2010) Global climate change amplifies the entry of tropical species into the Eastern Mediterranean Sea. Limnol Oceanogr 55(4):1478–1484. doi:10.4319/lo.2010.55.4.1478

Rand TA, Louda SM (2006) Invasive insect abundance varies across the biogeographic distribution of a native host plant. Ecol Appl 16(3):877–890

Restoration Coordination and Verification (RECOVER (2005) The RECOVER team's recommendations for interim goals and interim targets for the Comprehensive Everglades Restoration Plan: final report, 10 Jan 2005

Ricciardi A (2001) Facilitative interactions among aquatic invaders: is an "invasion meltdown" occurring in the Great Lakes? Can J Fish Aquat Sci 58:2513–2525

Ricciardi A, Cohen J (2007) The invasiveness of an introduced species does not predict its impact. Biol Invasions 9:309–315

Robinet C, Roques A, Pan H, Fang G, Ye J et al (2009) Role of human-mediated dispersal in the spread of the pinewood nematode in China. PLoS One 4(2):e4646. doi:10.1371/journal.pone.0004646

Rodriguez-Cabal MA, Noelia Barrios-Garcia M, Simberloff D (2009) Across island and continents, mammals are more successful invaders than birds (Reply). Divers Distrib 15:911–912

Santini A, Montaghi A, Vendramin GG, Capretti P (2005) Analysis of the Italian Dutch elm disease fungal population. J Phytopathol 153(2):73–79

Sheppard CS, Burns BR, Stanley MC (2014) Predicting plant invasions under climate change: are species distribution models validated by field trials? Glob Chang Biol 20(9):2800–2814. doi:10.1111/gcb.12531, Epub 2014 Apr 26

Shine C, Williams NM, Burnhenne-Guilmin F (2005) Legal and institutional frameworks for invasive alien species. In: Mooney HA, Mack RN, McNeely JA, Neville LE, Schei PJ, Waage JK (eds) Invasive alien species: a new synthesis. Island Press, Washington, DC, pp 233–284
Shine C, Kettunen M, ten Brink P, Genovesi P et al (2009) Technical support to EU strategy on invasive alien species (IAS) – Recommendations on policy options to minimize the negative impacts of invasive alien species on biodiversity in Europe and the EU. Final report for the European Commission. Institute for European Environmental Policy (IEEP), Brussels, Belgium, 35 p
Simpson A, Jarnevich C, Madsen J, Westbrooks R et al (2009) Invasive species information networks: collaboration at multiple scales for prevention, early detection, and rapid response to invasive alien species. Biodiversity 10(2–3):5–13
Stoett P (2009) Scaled linkage in policy co-ordination: catching invasive alien species in a global governance web. In: Paper presented to the 2009 Amsterdam conference on the human dimensions of global environmental change, Amsterdam
UNEP (United Nations Environmental Programme) (2002a) COP 6 Decision VI/26. Strategic plan for the convention on biological diversity. The Hague, 7–19 Apr 2002. Available at http://www.cbd.int/decisions/?dec=VI/26
UNEP (United Nations Environmental Programme) (2002b) COP 6 Decision VI/23. Alien species that threaten ecosystems, habitats or species. The Hague, 7–19 Apr 2002. Available at http://www.cbd.int/decisions/?id=7197. Last accessed Sept 2012
UNEP-WCMC (2011) Developing ecosystem service indicators: experiences and lessons learned from sub-global assessments and other initiatives, Secretariat of the Convention on Biological Diversity, Montreal, Canada, CBD Technical Series 58, 118 p. http://www.cbd.int/doc/publications/cbd-ts-58-en.pdf. Accessed 4 Sept 2013
Vilá M, Basnou C, Gollasch S, Josefsson M et al (2009) One hundred of the most invasive alien species in Europe. In: Drake JA (ed) Handbook of alien species in Europe. Springer, Berlin, pp 133–264
Vilà M, Basnou C, Pyšek P, Josefsson M (2010) How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. Front Ecol Environ 8:135–144
Vilà M, Espinar JL, Hejda M, Hulme PE et al (2011) Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecol Lett 14:702–708
Volin JC, Lott MS, Muss JD, Owen D (2004) Predicting rapid invasion of the Florida Everglades by Old World Climbing Fern (*Lygodium microphyllum*). Divers Distrib 10:439–446
Warren CR (2007) Perspectives on the alien' versus native' species debate: a critique of concepts, language and practice. Prog Hum Geogr 31(4):427–446
Whitman Miller A (2000) Assessing the importance of biological attributes for invasion success: Eastern Oyster (*Crassostrea virginica*) Introductions and associated Molluscan Invasions of Pacific and Atlantic Coastal Systems, Avail. UMI, Order No. DA3001170. (2000), 305 p. From: Diss Abstr Int B 62(1):47 (2001)
Winfield IJ, Fletcher JM, James JB (2011) Invasive fish species in the largest lakes of Scotland, Northern Ireland, Wales and England: the collective UK experience. Hydrobiologia 660:93–103
Zenetos A, Katsanevakis S, Poursanidis D, Crocetta F et al (2011) Marine alien species in Greek Seas: additions and amendments by 2010. Mediterr Mar Sci 12(1):95–120
Zenetos A, Gofas S, Morri C, Rosso A et al (2012) Alien species in the Mediterranean Sea by 2012. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD). Part 2. Introduction trends and pathways. Mediterr Mar Sci 13(2):328–352
Zenetos A, Koutsogiannopoulos D, Ovalis P, Poursanidis D (2013) The role played by citizen scientists in monitoring marine alien species in Greece. Cah Biol Mar 54(3):419–426