# Chapter 4. Impacts of invasive alien species on nature, nature's contributions to people, and good quality of life[1]

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# Chapter 4. Impacts of invasive alien species on nature, nature's contributions to people, and good quality of life

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# Executive summary

**1. Invasive alien species impact nature at all ecological levels, from native individuals, populations, species, to communities and ecosystems (*well established*) {4.3.1}.** Although some invasive alien species can have both positive and negative impacts (*well established*) {4.3, 4.4, 4.5, 4.6}, the overall negative impacts of invasive alien species far exceed any positive impacts on nature and humans (*established but incomplete*) {4.3.1, 4.4.1, 4.5.1, 4.6.1, 4.6.3}. Almost three-quarters (71 per cent) of the documented impacts on nature adversely affect native species (*well established*) {4.3.1}. The magnitude of impacts of invasive alien species varies depending on the geographic and environmental context (*well established*) {4.3.1, 4.3.2, 4.3.3, 4.4.1, 4.4.2, 4.4.3, 4.5.1, 4.5.2, 4.5.3, 4.6.1, 4.6.2, 4.6.3, 4.6.4, 4.6.5}. The most commonly observed impacts on nature are changes in ecosystem properties, reductions in the performance of native species and declines in local populations of both plants and animals (*well established*) {4.3.1.3}. The most frequently observed mechanisms of impacts are competition, physical and chemical changes of the invaded ecosystems and trophic interactions through predation and herbivory (*well established*) {4.3.1.3}. In terrestrial ecosystems, most studies of impacts on nature are documented from plants and occur in forests, grasslands and human-dominated habitats (*well established*) {4.3.2.1}. Few impacts on nature are documented from very cold (tundra and high mountain habitats), very dry (deserts and xeric shrub lands) or flooded terrestrial habitats (wetlands – peatlands, mires, bogs) (*well established*) {4.3.1}. No impacts have been documented in the cryosphere and the deep-sea (*established but incomplete*) {4.3.1, Table 4.2}. The magnitude of negative impacts of invasive alien species often varies with the invaded biomes and species, and impacts are sometimes exacerbated or attenuated by the interaction of invasive alien species with other drivers such as climate change, changes in land- and sea-use, or pollution (*established but incomplete*) {4.3.1, Box 4.5}. The number of documented impacts of invasive alien species has risen in parallel with the documented number of alien species (established but incomplete) {4.3.1}. About 7 per cent of alien plants, 17 per cent of alien vertebrates, 23 per cent of alien invertebrates, and 12 per cent of alien microbes are known to be invasive, but their numbers are likely an underestimate (*established but incomplete*) {4.2}.

**2. Invasive alien species have contributed to local or global extinctions of native species (*well established*) {4.3.1, Box 4.4}.** Of all invasive alien species with documented impacts, 6 per cent (218 invasive alien species) have been associated with the local extinction of at least one native species (*established but incomplete*) {4.3.1}. Invasive alien species are a significant factor that directly or indirectly caused 60 per cent of documented global animal and plant extinctions (*established but incomplete*) {Box 4.4} and have caused 1,215 documented local extinctions of 255 native species across all taxa (established but incomplete) {4.3.1}. These local extinctions have been documented in marine (23.2 per cent) freshwater (14.5 per cent) and terrestrial realms (62.1 per cent) (*well established*) {4.3.1}. Invasive alien animals (vertebrates 51 per cent, invertebrates 32.5 per cent) are more often implicated in causing local extinctions than invasive alien plants (15.3 per cent) and microbes (1.2 per cent) (*well established*) {4.3.1}.

**3. Impacts of invasive alien species are more harmful to isolated ecosystems, such as islands, than elsewhere (*established but incomplete*) {4.3.1.1}.** Documented negative impacts on native species on islands are far more frequent than positive impacts (40.5 per cent vs. 4.5 per cent) (*well established*) {4.3.1.1}. Of the global extinctions caused by invasive alien species, the overwhelming majority occurred on islands and other isolated ecosystems (*established but incomplete*) {4.3.1, Box 4.4}. Local extinctions are more frequently documented from islands than from non-island locations (9.2 per cent vs. 4.0 per cent) (*well established*) {4.3.1}. Of the top ten invasive alien species documented to have caused local extinctions on islands, five are domesticated or synanthropic species: *Rattus* spp. (rats), *Capra hircus* (goats), *Mus musculus* (house mouse), *Felis catus* (cat), but also other vertebrates such as *Anas platyrhynchos* (mallard) (*well established*) {4.3.1.1}.

**4. Invasive alien species pose a substantial threat to the conservation of native biodiversity, landscapes and seascapes in protected areas (*established but incomplete*) {4.3.1.2}.** Invasive alien species impact areas protected for nature conservation, with impacts of similar magnitude and frequency occurring both inside and outside protected areas (*established but incomplete*) {4.3.1.2}. Impacts on nature in protected areas constitute 19.3 per cent of the total number of documented impacts on nature (*established but incomplete*) {4.3.1.2}. Reports of negative impacts on native species in protected areas are far more frequent than positive impacts (33.2 per cent vs. 6.3 per cent) (*established but incomplete)* {4.3.1.2}.

**5. Invasive alien species cause impacts on all categories of nature's contributions to people (*well established*) {4.4}.** A large majority (80 per cent) of documented impacts on nature's contribution to people are negative and harm people by decreasing ecosystem services (*well established*) {4.4.1}. The most commonly observed negative impact of invasive alien species to nature's contributions to people is a reduction of human food supply (*well established*) {4.4.1}, which is caused by all taxa, in all regions and realms (*well established*) {4.4.2, 4.4.3}. Other important impacts of invasive alien species on nature's contributions to people are on habitat maintenance (16 per cent records) and on the provision of materials, companionship and labour (14 per cent records). In terrestrial systems, the most common invasive alien species causing impacts are plants, particularly in cultivated areas and in temperate and boreal forests (*well established*) {4.4.2.1}. In inland waters, 70 per cent of the documented impacts on nature's contributions to people are from inland surface waters and water bodies/freshwater (*well established*) {4.4.2.2}, and most of them are caused by invasive alien vertebrates (*well established*) {4.4.2.2}. In marine systems, the impacts are mostly caused by invasive alien invertebrates and predominate in shelf ecosystems (*well established*) {4.4.2.3}.

**6. Impacts of invasive alien species on human health vary from nuisance to poisoning, disease and death (*well established*) {4.5.1}**. Zoonotic diseases transmitted by invasive mosquitos inflict misery, chronic disease and death (*well established*) {4.5.1.3}. Invasive alien plants can be highly allergenic or phytotoxic (*well established*) {4.5}. Several invasive ant species have been documented as causing serious allergic or toxic reactions (*well established*) {4.5.1.3}. Health impacts caused by venomous and poisonous invasive alien marine species have frequently been documented in the Mediterranean Sea (*well established*) {4.5.1.3}.

**7. Global cumulative damages due to invasive alien species totalled more than US$ 1.738 trillion between 1970 and 2020 (*established but incomplete*) {Box 4.13}.** In 2017 alone, documented aggregate global costs of biological invasions were estimated to reach US$162.7 billion, exceeding the 2017 gross domestic product of 52 of the 54 countries on the African continent, and more than twenty times higher than the combined total funds available in 2017 for the World Health Organization and the United Nations (*established, but incomplete*) {Box 4.13}. In 2019, global annual costs of biological invasions were estimated to exceed $423 billion, with variations across regions, but this is likely a gross underestimation (*established but incomplete*) {Box 4.13}. North America (53 per cent) and Asia (13 per cent) were associated with the highest documented costs, which is partly driven by cost data incompleteness for most taxa and regions of the world (*well established*) {Box 4.13}. Agriculture is the economic sector most frequently documented as affected by invasive alien species and specifically by insects which are often categorized as pests (*established but incomplete*) {Box 4.13}.

**8. Invasive alien species cause impacts on good quality of life that affect the opportunities for people to live a fulfilled life (*established but incomplete*) {4.5}.** The majority of the 3,783 documented impacts on good quality of life are documented as negative for people (about 85 per cent) (*established but incomplete*) {4.5.1}. Most negative impacts (56 per cent) on good quality of life are the result of changes to "material and immaterial assets" by invasive alien species (*established but incomplete*) {4.5.1, 4.5.2, 4.5.3}. Invertebrates are documented as causing the highest number of negative impacts on good quality of life (51 per cent of negative impacts) (*established but incomplete*) {4.5.3}. Conversely, plants (responsible for 42 per cent of positive impacts) are more likely to result in positive impacts on good quality of life (*established but incomplete*) {4.5.3}. Negative and positive impacts on society are most often documented in Asia-Pacific (41 per cent of negative impacts and 53 per cent of positive impacts), and in cultivated areas (29 per cent of negative impacts and 26 per cent of positive impacts) (*established but incomplete*) {4.5.2.1, 4.5.3}. Although there is very little systematic research on gender differences in impacts of invasive alien species, the available data suggest that some invasive alien species may cause gender-differentiated impacts (*established but incomplete*) {4.5.1}.

**9. Indigenous Peoples and local communities report more negative than positive impacts caused by invasive alien species, especially on water resources, human health and health of livestock and access to traditional lands (*well established*) {4.6.1}.** Indigenous Peoples and local communities report ten times more negative than positive impacts caused by invasive alien species on nature (92 per cent negative, 8 per cent positive) (*well established*) {4.6.1}. Impacts on nature, often affect the deep kinship connection that many Indigenous Peoples and local communities have with nature (*well established*) {4.6.3}. When considering nature's contributions to people, reports are more balanced (55 per cent negative to 45 per cent positive) (*well established*) {4.6.2}. Two-thirds (68 per cent) of the impacts on the good quality of life of Indigenous Peoples and local communities have been documented as negative, compared to one-third (32 per cent) that have been documented as positive (*well established*) {4.6.3}. Invasive alien species have frequently been documented to cause the loss of access to and mobility within traditional lands, leading to harder labour requirements (*well-established*) {4.6.3}. Negative impacts on the health of Indigenous Peoples and local communities can be direct (e.g., injury) and indirect, including general feelings of despair and stress. Some invasive alien species can provide some benefits, including income and development of local industry (*well established*) {4.6.3, 4.6.4}, but Indigenous Peoples and local communities highlight that seemingly positive impacts are not often considered wholly positive by their communities, especially when communities had little agency or choice in responding to the invasive alien species (*well established*) {4.6.2, 4.6.3, 4.6.4}. There are many cases where Indigenous Peoples and local communities have adapted to the negative impacts of invasive alien species (*well established*) (4.6.3). Whilst more negative impacts have been documented on cultural values and practices, involvement of Indigenous Peoples and local communities in the use and management of invasive alien species is, in some cases, also documented as an opportunity for skills development and knowledge transfer (*established but incomplete*) {4.6.5}.

**10. There are substantial geographic and taxonomic gaps in the documentation, quantification and understanding of impacts (*established but incomplete*) {4.7.2}.** The quality and quantity of information available on impacts of invasive alien species for different taxa, units of analysis, regions and realms differ greatly, and research efforts are unevenly distributed across regions, temporal scales, and taxa (*well established*) {4.7.2}. These biases can be observed across all realms, especially in marine ecosystems, where the extent and timing of research efforts on marine invasive alien species lag behind terrestrial studies (*established but incomplete*) {4.7.2}. About 95 per cent of the sources listed in the dataset are in English, severely underrepresenting studies only available in non-anglophone sources (*well established*) {4.7.2}.

# 4.1. Introduction

> "The cardoon (*Cynara cardunculus*) has a far wider range: it now occurs in these latitudes on both sides of the Cordillera, across the continent. I saw it in unfrequented spots in Chile, Entre Rios, and Banda Oriental. In the latter country alone, very many (probably several hundred) square miles are covered with one mass of these prickly plants and are impenetrable by man or beast. Over the undulating plains, where these great beds occur, nothing else can live. Before their introduction, however, I apprehend the surface supported as in other parts a rank herbage. I doubt whether any case is on record, of an invasion of so grand a scale of one plant over the aborigines." (Darwin, 1839).

At the time Charles Darwin wrote this, European powers vied to import, grow and disseminate "exotic" plants and animals. The earliest "jardins d'acclimatation" were erected on the order of the King of France at the time, Louis XV, to accommodate edible, medicinal and decorative plants elsewhere; breadfruit from the South Pacific was shipped to French Guiana, and coffee plants to the Antilles and Brazil (Bailey, 2018). This was the continuation of a process rooted in prehistorical millennia. Zooarchaeological and archaeobotanical studies reveal the spread of the Near Eastern suite of domesticates, cultivated plants and synanthropic biota across Europe, Asia and Africa (Bortolus et al., 2015; Colledge et al., 2013; **Chapter 1**, **Figure 1.3**). Austronesian people transported their domesticated animals, including dogs, pigs, chickens and the synanthropic *Rattus exulans* (Pacific rat) to isolated archipelagos of Remote Oceania long before the sixteenth century (N. Amano et al., 2021; Crabtree, 2016; Giovas, 2006). The direct and indirect impacts of these species on island ecosystems (**Glossary**), through agricultural deforestation and the introduction of mammalian predators, have only recently come to the fore: palaeoecological data reveal losses of many species (Drake & Hunt, 2009; Fillios et al., 2012; Prebble & Wilmshurst, 2009).

Despite vast numbers of terrestrial, inland waters, and marine introductions over millennia, written documentation of their impacts was rare until the twentieth century. For example, *Sporobolus alterniflorus* (smooth cordgrass) occupying subtropical and temperate salt marshes along the Atlantic coast of South America may have been introduced in the eighteenth or early nineteenth century, but remained a "hidden invasion"; its impacts on coastal geomorphology and biodiversity have been overlooked and undocumented (Bortolus et al., 2015). Studies that actually document impacts of invasive alien species have been limited to 3515 invasive alien species, about 10 per cent of all alien species (**Glossary**) according to the Global Register of Introduced and Invasive Species (GRIIS).

Charles Elton evinced great interest in biological invasions (**Glossary**) as early as the 1930s. Studying a bevy of introduced species in the United Kingdom, from *Ondatra zibethicus* (muskrat) to *Rattus norvegicus* (brown rat), he denounced them as a zoological catastrophe. Elton's seminal contribution (Elton, 1958) highlighted the impacts of invasive alien species – animals, plants, pathogens, terrestrial, aquatic and marine – and raised public awareness of biological invasions as a conservation issue (Simberloff, 2010). Still, it was not until the 1980s, when the Scientific Committee on Problems of the Environment (SCOPE) convened a series of workshops, that contemporary invasion biology was launched (Mooney & Drake, 1989; Simberloff et al., 2013) and soon established that invasive alien species could have severe and lasting impacts on ecosystem functions, and that nearly every type of ecosystem had been affected (Lodge, 1993; **Chapter 1**, **Figure 1.2**). The mode, rate, order and crypticity of introduction, the inherent complexity in interactions between invasive alien species population and host community and ecosystem, and their interactions with the environment are each context-driven and difficult to assess (Jarić et al., 2019; Parker et al., 1999; Vanderhoeven et al., 2017; **Chapter 1**, **section 1.5**).

Invasive alien species cause a wide array of economic damage, disrupting the production of goods and services. For example, invasive alien species can reduce timber and agricultural output (T. P. Holmes et al., 2009; Paini et al., 2016), damage infrastructure (Fritts, 2002), impact the operations of public utility companies (Elliott et al., 2005; Magara et al., 2001), and disrupt navigation (Ashe & Driscoll, 2013; Bryson et al., 2008; Grewell et al., 2016; Lindgren et al., 2013; Mallison et al., 2001). Invasive alien species are also notorious for altering nature's contributions to people and good quality of life (**Glossary**), which affects property values (Olden & Tamayo, 2014), tourism (Mejía & Brandt, 2015), and outdoor recreation (Lauber et al., 2020). Human health can be profoundly affected, too (Juliano & Lounibos, 2005; Kemp et al., 2000; World Health Organization & Convention on Biological Diversity, 2015). Significant costs are also associated with invasive alien species prevention and control efforts (**Glossary**), including clearing costs (Marais et al., 2004) and increased costs of transportation (e.g., road-right-of-way maintenance costs, hull maintenance, inspection stations, ballast water treatment system costs, etc.). Invasive alien species are sometimes associated with economic benefits, having been deliberately introduced for aquaculture (De Silva et al., 2009), forestry and landscaping (Knowler & Barbier, 2005; Richardson, 1998), cultural reasons (Pejchar & Mooney, 2009), or recreational pursuits such as sport fishing, yet there is general agreement that their net economic effect is overwhelmingly negative (Bradshaw et al., 2016; Diagne, Leroy, et al., 2021; Zenni et al., 2021).

Though related literature has increased in recent years, research on the economic benefits and costs of invasive alien species is in its infancy. Perhaps more concerning, researchers are still trying to understand the links among biological invasions and economic activities, some of which are indirect and difficult to quantify (B. A. Jones & McDermott, 2018; B. A. Jones, 2016; Charles & Dukes, 2007). As a result, few long-term studies examine economic impacts over time (Essl et al., 2011; Cuthbert, Pattison, et al., 2021). As invasive alien species continue to spread and understanding about the economic implications of invasive alien species increases, it is safe to assume that the estimate of sustained damages will continue to rise. Perceptions of the costs and benefits of introduced species are varied (Jubase et al., 2021; R. T. Shackleton, Richardson, et al., 2019; Verbrugge et al., 2013; **Chapter 1**, **section 1.5.2**). A limited number of invasive alien species are exploited commercially, though some of those have had substantial negative impacts in recipient ecosystems. In 1999, the International Union for the Conservation of Nature (IUCN), through its Invasive Species Specialist Group (ISSG), established the list of "100 of the world's worst invasive alien species" to increase public awareness (GISD, 2013). Geraldi et al. (2019), examined media attention to the aquatic and marine species on the IUCN list and concluded that coverage was low and short-lived; an important observation given the influence of media on societal environmental perceptions. Listed by the IUCN (but unexamined by Geraldi et al., 2019) are *Oncorhynchus mykiss* (rainbow trout) and *Salmo trutta* (brown trout), which have been introduced worldwide for the main purpose of recreational fishing and have subsequently resulted in significant losses of biodiversity (Cambray, 2003). Yet, the growing popularity of sport fishing and angling delivers significant economic benefits to tourism, rending these and similarly introduced invasive fish "sacrosanct" amongst some stakeholders (J. E. Jackson et al., 2004; Lewin et al., 2006). Despite this inherent complexity, this chapter provides a global analysis and synthesis of the environmental, economic and social impacts of invasive alien species from available evidence (published peer-reviewed literature, grey literature, and information from Indigenous and local knowledge systems; **Glossary** and **Box 4.1**). This assessment only reflects documented impacts; however, the total impact of invasive alien species remains unknown.

**Box 4.1. Rationale of the chapter**

The chapter focuses on the impacts of invasive alien species on nature (**Glossary**) and nature's contributions to people and a good quality of life, as defined in the conceptual framework of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES;

**Chapter 1**, **sections 1.6.1**), including non-economic values (e.g., cultural, social and shared, recreational, scientific, spiritual and aesthetic values).

**Guiding questions:**

- Which native taxa, nature's contributions to people and components of good quality of life are most negatively and positively impacted by invasive alien species?
- Which units of analysis and regions are most negatively and positively impacted by invasive alien species?
- Which invasive alien species caused local and global extinctions and which native species (**Glossary**) and taxonomic groups are affected?
- What are the global monetary costs of invasive alien species?
- How do people, including Indigenous Peoples and local communities, assess the magnitude of impacts of invasive alien species?
- What are our knowledge gaps and biases in the type and distribution of impacts across taxa, regions, units of analysis?

**Key words:**

positive and negative impacts, invasive alien species, nature's contributions to people, good quality of life, native taxa, Indigenous Peoples and local communities, units of analysis

The chapter flows from an unprecedented assessment of impacts, through which an impact database has been compiled. **Section 4.1** introduces the major concepts underpinning the analysis of impacts; **section 4.2** presents the methodology employed to record and analyse impacts in the chapter; **section 4.3** presents the analysis and synthesis of impacts on nature; **section 4.4** covers impacts on nature's contributions to people; and **section 4.5** describes impacts on good quality of life. For each section, the team of authors have presented general patterns, impacts by realm and units of analysis, impacts by region, and impacts by invasive alien species taxon. **Section 4.6** presents a summary of some impacts as perceived by Indigenous Peoples and local communities; and **section 4.7** discusses the future direction of impacts and their analysis, including the use of scenarios and modelling, and the knowledge gaps that can animate future improvements in methodology. Recording and analysing the impacts of invasive alien species will inform future efforts toward prevention and management (**Glossary**) of biological invasions.

### 4.1.1. Types of impacts: nature, nature's contributions to people, good quality of life

The impacts of invasive alien species on nature, nature's contributions to people, and good quality of life are all context-dependent, and range along a continuum from nearly indiscernible to region-wide changes (**Chapter 1**, **Figure 1.1** for definitions).

**Impact on nature**, formerly "ecological impact", is defined as a measurable change to the properties of an ecosystem (Ricciardi et al., 2013), and implies that all introduced species can have an impact, even when not yet established or widespread (**Glossary**), which may vary in magnitude, simply by integration into the ecosystem. Impact can be measured at the level of an organism (e.g., effects on individual mortality and growth), a population (abundance), a community (species richness, evenness, composition, trophic structure), an ecosystem (physical habitat, nutrient cycling, contaminant cycling, energy flow), or a region (species richness, beta diversity). Individual, population and community-level impacts are most commonly studied (Jeschke et al., 2014; Ricciardi et al., 2013).

**Impact on nature's contributions to people** (**Chapter 1**, **Box 1.12**) comprises positive contributions as well as negative impacts, e.g., exacerbating fire hazards, soil erosion, allergenic pollen, zoonotic diseases, poisoning and envenomation (Vaz et al., 2017). Regardless of taxon, ecosystem and region, invasive alien species alter nature's contributions to people by affecting populations, community dynamics, ecosystem processes, and abiotic variables. Yet, despite awareness of the susceptibility of nature's contributions to people to alteration by invasive alien species, research has lagged behind and impacts are often overlooked or underappreciated, leaving threats to people unquantified (Charles & Dukes, 2007).

**Each constituent of good quality of life** (**Chapter 1**, **Table 1.4**) is vulnerable to alteration by invasive alien species. Changes to the constituents of good quality of life such as material and immaterial assets (e.g., the provisioning of food and fuel), safety, health, economic and cultural practices, social relations, or freedom of choice and action can affect peoples' lives (**Box 4.9** in **section 4.3.2.1**, for example).

Appreciation of the extent and intensity of impacts is essential for prioritizing appropriate policy and governance (**Glossary**) responses to invasions. Attention of policymakers, stakeholders and the public is focused on a subset of introductions perceived as "harmful", having resulted in extinction or extirpation of native species and/or striking changes to ecosystem functioning, nature's contributions to people and good quality of life (Simberloff et al., 2013).

### 4.1.2. Directionality of impacts: nature, nature's contributions to people, good quality of life

Impact directionality (i.e., whether impacts of invasive alien species are assessed as "negative" or "positive") is partly grounded in subjective perceptions embedded within economic, cultural and social contexts. Perception of impacts as positive or negative depends on value systems and values can vary even within the same economic, cultural and social context (R. T. Shackleton, Richardson, et al., 2019). Thus, there are different ways of defining whether nature or its elements are harmed or benefit.

Nature and its elements have intrinsic value, and one could argue that this value can be damaged by invasive alien species. Extinctions and extirpations caused by the unintentional introductions of rats, snakes, gypsy moths, and chestnut blight, can be considered negative impacts (Czech & Krausman, 1999; Butchart et al., 2006; Kochalski et al., 2019). Local population losses and niche contraction of native species may not induce immediate extirpation, but they augur reduction of genetic diversity, loss of functions, processes, and habitat structure, increasing the risk of decline and extinction (**Glossary**; Galil, 2007). When studies document cases of rising species richness or abundance of native species following introductions of an invasive alien species (Irigoyen et al., 2011; McQuaid & Griffiths, 2014; Thomsen, 2010), they can be considered as positive impacts on nature. However, this assessment recognises that the purported benefits can be predicated on provision of novel habitat (e.g., polychaete and oyster reefs in muddy habitats, algal meadows) by transforming entire habitats to the detriment of the pre-existing community. In many communities, some native species suffer from the introduction of invasive alien species while others may benefit.

In this assessment, impacts on nature are defined as negative when a native species suffers disadvantage, following the Environmental Impact Classification for Alien Taxa (EICAT, **Box 4.2**) approach developed by IUCN (2020), and as positive when a native species benefits from ecosystem changes due to the introduction of an invasive alien species (Vimercati et al., 2022). However, not every ecosystem change can be assigned a unique directionality. For example, abiotic characteristics of ecosystems (e.g., changes in soil or water chemistry, structural complexity) can increase or decrease due to the impacts of an invasive alien species, but it is not straightforward to assign an impact direction (positive or negative) because these changes might have different consequences for different species. Moreover, abiotic ecosystem changes can sometimes be quantified as either an increase or a decrease of an indicator (e.g., an increase in the concentration of hydrogen ions (H+) is equivalent to a decrease of the pH). Thus, in this report, impacts describing abiotic changes in ecosystem characteristics are classified as negative or positive only if the consequence of these changes is documented to harm or benefit a native species. Abiotic ecosystem changes are not assigned a directionality when it is unknown if a native species suffers or benefits from these changes. Invasive alien species can benefit or harm people, which determines the directionality of impacts on nature's contributions to people and good quality of life. Directional changes in nature's contributions to people (i.e., increases or decreases of the parameters that are measured, **Chapter 1**, **Box 1.12**) may be positively or negatively associated with changes in good quality of life. For this report, benefits in nature's contributions to people are documented as an increase in services and/or decrease in disservices, whereas deleterious changes would do the opposite (Vaz et al., 2017). By contrast, in this report, directionality in good quality of life is assessed by changes in constituents of good quality of life (Bacher et al., 2018; **Chapter 1**, **Table 1.4**) which are directly associated with humans profiting or suffering from the impacts of an invasive alien species. This follows the Socio-Economic Impact Classification for Alien Taxa (SEICAT; **Box 4.2**) approach, which recognizes that different people may perceive impacts by invasive alien species in different ways (Bacher et al., 2018). Invasive alien species may cause a range of impacts with different directionality ("negative" and "positive") on native species of the resident community, on categories of nature's contributions to people, and on components of good quality of life. For example, a negative impact of an invasive alien species on a native predator may profit its native prey; an invasive alien species may increase food production at the expense of soil deterioration; or an invasive alien rangeland plant like *Echium plantagineum* (Paterson's curse) may profit bee keepers due to its proliferous nectar production, but be toxic to livestock and thus detrimental to farmers (Harris, 1984). Thus, impacts on nature can be at odds with impacts on nature's contributions to people and good quality of life. For instance, *Gambusia affinis* (western mosquitofish**)** has been widely introduced as a biological control agent (**Glossary**) to manage mosquito populations but also preys on rare indigenous fish, amphibians and invertebrates (Englund, 1999; Leyse et al., 2004; Segev et al., 2009; Rupp, 1996).

Occasionally, invasive alien species impact all three (**Table 4.1**) – nature, nature's contributions to people and good quality of life – as is the case with *Acacia mearnsii* (black wattle), in South Africa. This highly invasive alien species manifests significant negative impacts on water resources (losses estimated at 577 million $m^3$ annually), biodiversity, and the stability and integrity of riparian ecosystems, while supplying an industry of tanning agents and providing rural communities with firewood and building materials. Plantation owners, small growers and rural communities benefit economically from the products of invasive alien wattles, whereas most sectors of society bear the social and monetary costs of loss in water and biodiversity, and increase in fire risk and erosion (de Wit et al., 2001).

When interpreting invasive alien species impacts, care should be taken to examine them in a comprehensive manner, addressing nature, nature's contributions to people, good quality of life, and their directionality. Reporting all types of impacts, positive and negative, separately allows a comprehensive picture of impacts by invasive alien species and avoids some impacts being masked by tallying or calculating "net impacts". For example, economic benefits are often gained by a few people or sectors while costs, often long-term ones, are borne by many others (Gozlan & Newton, 2009; Kelsch et al., 2020).

The IPBES invasive alien species assessment acknowledges that the outcomes of assessments of the positive impacts of invasive alien species do not balance or offset their negative impacts, which may be irreversible (Lockwood et al., 2023). Positive and negative stacked bar charts in this chapter do not imply that positive and negative impacts can be summed.

**Box 4.2. Environmental and Socio-Economic Impact Classification for Alien Taxa: EICAT and SEICAT**

The International Union for Conservation of Nature (IUCN) EICAT framework was developed to categorize and assess negative impacts caused by alien taxa on native taxa (IUCN, 2020). The framework assesses how much a native species is affected by an invasive alien species. Other types of environmental impacts such as changes caused by alien taxa to abiotic ecosystem properties (e.g., soil or water chemistry) are considered under the framework only if such changes lead to a decrease in attributes of native biodiversity.

The EICAT classifies impacts in a 5-step semi-quantitative scale based on the level of biological organization affected (individuals → populations → communities), and the magnitude and reversibility of these impacts (Blackburn et al., 2014). The five steps reflect an increase in the order of magnitude of the particular impact so that a new level of biological organization is involved. **Minimal Concern** – negligible impacts, and no reduction in performance of a native taxon's individuals; **Minor** – performance of individuals reduced, but no decrease in population size; **Moderate** – native taxon population decline; **Major** – native taxon local extinction (i.e., change in community structure), which is naturally reversible; and **Massive** – naturally irreversible local or global extinction of a native taxon (**Figure 4.1**; IUCN, 2020; Volery et al., 2020). Impacts of invasive alien species can be caused through 10 mechanisms (**Figure 4.1**). The EICAT is conceptually and structurally related to the IUCN Red List of Threatened Species, with the Red List categorizing a focal native species based on its risk of extinction, and the EICAT categorizing a focal alien taxon based on the degree to which it has negatively impacted native taxa (Van der Colff et al., 2020).

The SEICAT assesses negative impacts of invasive alien species on good quality of life (Bacher et al., 2018). It follows an approach similar to the EICAT. In particular, it classifies changes in human activities caused by invasive alien species into one of 5 magnitudes. These are: **Minimal Concern** – negligible impacts, and no reduction in individual peoples' activities; **Minor** – normal activities are more difficult, but no decrease in activity size, i.e., all people still carry out the activity; **Moderate** – decline in activity size, i.e., fewer people participate in an activity; **Major** – local disappearance of an activity from all or part of the area invaded by the invasive alien species, which is naturally reversible; and **Massive** – local irreversible disappearance of an activity from all or part of the area invaded by the invasive alien species (Bacher et al., 2018). Changes in human activities can be caused through impacts on five constituents of good quality of life (**Box 4.3**). The framework is based on the capability approach of welfare economics (Robeyns, 2005; Sen, 1999) and thus avoids ambiguities in interpreting impacts based on monetary approaches (Hoagland & Jin, 2006).

The EICAT and the SEICAT have been used to compare impact magnitudes of alien taxa at various spatial scales, across geographic regions and taxonomic groups (e.g., Evans et al., 2016, 2020; Canavan et al., 2019; Galanidi et al., 2018; Kesner & Kumschick, 2018; Volery et al., 2021), and to facilitate evidence-based prioritization and other management decisions (Rockwell-Postel et al., 2020). Widespread application of both schemes is expected to reduce data biases and data gaps on the impacts of invasive alien species on nature and good quality of life. Recently, the EICAT framework was expanded to include a classification for positive impacts of invasive alien species for nature (EICAT+; Vimercati et al., 2022) but this was not available at the time when data for this chapter were gathered. EICAT+ might allow comparison of positive and negative environmental impacts in a common framework for a better understanding of the consequences of invasive alien species and to better inform conservation decisions. For a comprehensive understanding and efficient management, the reporting of both negative and positive impacts is critical (Vimercati et al., 2020).

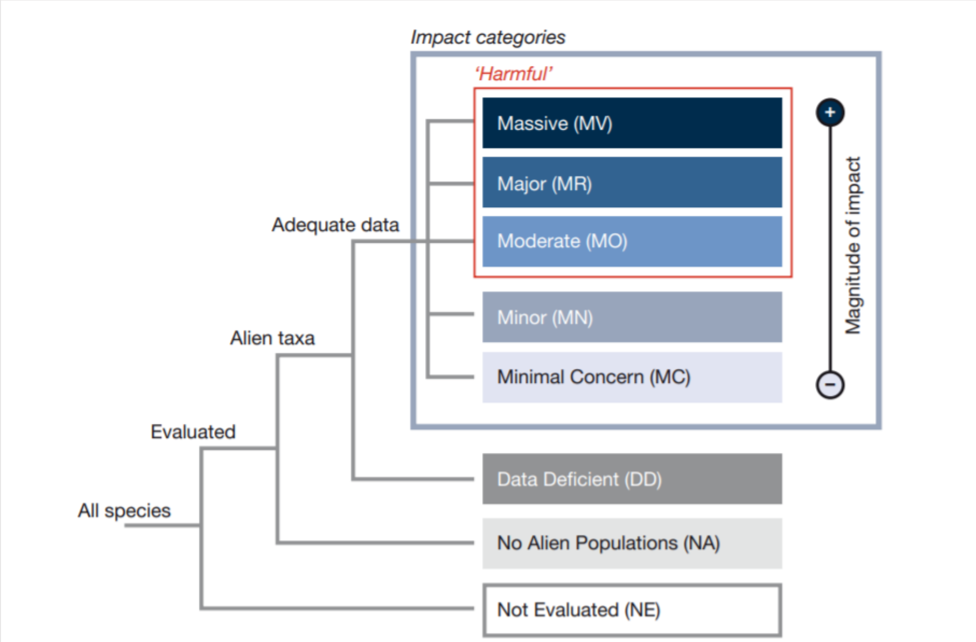


**Figure 4.1.** EICAT and SEICAT categories and the relationship between them. The five impact categories (from minimal concern to massive) can be used to assess negative impacts caused by invasive alien species (which are a subset of alien species). Source: IUCN (2020), https://doi.org/10.2305/IUCN.CH.2020.05.en, under license CC BY-NC 4.0.

### 4.1.3. Impacts and Indigenous and local knowledge

Some Indigenous Peoples and local communities, because of their holistic and interconnected relationships with nature (M. C. C. Holmes & Jampijinpa, 2013) and close dependence on nature for livelihoods and support systems (Mungatana & Ahimbisibwe, 2012), experience impacts of invasive alien species that go beyond changes to distinct species or habitats, to include both negative and positive economic, social and cultural impacts, including on good quality of life (Vaarzon-Morel, 2010; Sundaram et al., 2012; Jevon & Shackleton, 2015; K. Smith et al., 2010; dos Santos et al., 2014; Atyosi et al., 2019; Martínez & Manzano-García, 2019; R. T. Shackleton, Shackleton, et al., 2019). For some Indigenous Peoples and local communities, an impact of invasive alien species may change material assets, such as food and materials to sustain livelihoods (K. Smith et al., 2010), as well as some immaterial values, including cultural practices (Monterroso et al., 2011), opportunity for learning and teaching on traditional lands (Bach et al., 2019), and persisting spiritual identities (Fischer, 2007), all of which underpin their health and well-being (Sangha et al., 2015).

Reviews, such as the one conducted by Pfeiffer and Voeks (2008), highlight the importance of time scale in assessing impacts, and estimate that where an invasive alien species has been present for at least 3 generations (100 years plus), Indigenous Peoples and local communities may incorporate the invasive alien species into rituals, practices or as a resource. However, other studies (R. T. Shackleton et al., 2017) and frameworks (C. M. Shackleton et al., 2007) focused on sustainable livelihoods more broadly, suggest that if an invasive alien species is left unchecked over time, the negative impact on livelihoods and vulnerability of communities increases with longer exposure to the invasive alien species. For example, the Botswana San once embraced *Prosopis juliflora* (mesquite), planted by forestry officials in the 1980s, as a useful resource but, by the 1990s, its spread threatened animals, water sources and movement through the bush. Thus, the San people have since worked actively to eradicate (**Glossary**) it (Bach et al., 2019; Fischer, 2007; Monterroso et al., 2011; Mosweu et al., 2013; Sangha et al., 2015; K. Smith et al., 2010).

The nature of research on impacts of invasive alien species for Indigenous Peoples and local communities has also developed over time. Early studies often documented the knowledge and use of invasive alien species by Indigenous Peoples and local communities (i.e., ethnobotanical studies looking at medicinal or food use of alien plants; Bye, 1981), while more complex impacts were not documented. As Indigenous and local knowledge has been elevated within mainstream arenas to inform global biodiversity policies (e.g., Local Biodiversity Outlooks; Forest Peoples Programme et al., 2016, 2020), studies of Indigenous and local knowledge on broad ecological, social and cultural impacts have increased, including co-designed studies with Indigenous Peoples and local communities (e.g., Sloane et al., 2021; S. Russell et al., 2020). However, this recent rise in the number and complexity of studies does not mean that impacts have only recently been felt. For invasive alien species that arrived and spread centuries ago, the information about first impacts may not have been passed down through the generations of Indigenous Peoples or local communities, particularly if the introduced species is not part of ancestral or "Dreaming" stories and customs (Crowley, 2014; Salmón, 2000). Therefore, cultural stories and knowledge transferred in modern times may be more on how to use and adapt to invasive alien species, rather than documented negative impacts (e.g., rabbits in Australia, feral pigs in Hawaii, wild horses in North America, water hyacinth in waterways in Asia and Africa; Pfeiffer & Voeks, 2008; Collin, 2017).

Given the complexity of impacts considering time-scale and the diversity of Indigenous Peoples and local communities and their livelihoods, Pfeiffer and Voeks (2008) proposed a framework of invasive alien species impacts as either "impoverishing, augmenting, or facilitating" culture. Fitting within this framework, some studies recognize negative impacts of invasive alien species to the livelihoods of Indigenous Peoples and local communities (Kent & Dorward, 2015; Ngorima & Shackleton, 2019), others acknowledge the positive impacts such as facilitation of inter-generational culture retention (Maldonado Andrade, 2019), and some studies highlight the adaptation of some Indigenous Peoples and local communities to invasive alien species (P. L. Howard, 2019).

In this chapter, Indigenous and local knowledge sources have been included as data in the main impacts database (**section 4.2**) and, in addition, **section 4.6** includes a supplementary review of impacts directly documented by Indigenous Peoples and local communities from 124 peer-reviewed sources, which fills some information gaps in the mainstream database methods (**section 4.6**).[2]

[2] Data management report available at: https://doi.org/10.5281/zenodo.5760266

## 4.2. Methodology

Authors of this chapter have systematically reviewed relevant available information to understand the impact of invasive alien species on nature, nature's contributions to people and good quality of life, at a global level for a large number of organisms and habitats.

Some regions of the world have notably more information in scientific publications than others (Nuñez et al., 2019; Nuñez & Amano, 2021). Therefore, methods for reviewing literature varied within this chapter, with tailored criteria and systematic approaches for literature searches being adopted for different regions and taxa. The specific methodologies are presented in more detail in the data management report.[3] Reviewed information included scientific literature (papers, books) and grey literature (institutional reports, reports of agencies and other relevant sources), including from Indigenous and local knowledge, and databases of invasive alien species (e.g., Centre for Agriculture and Bioscience International (CABI)'s Invasive Species Compendium and the Global Invasive Species Database (GISD), the IUCN Red List of Threatened Species, or the InvaCost database).

From each analysed document, gathered data included:

- The geographical location of the impact.
- The corresponding IPBES unit of analysis (**Chapter 1**, **section 1.6.5** for a description of all 17 units of analysis), recording whether the impacted area was on an island or in a protected area.
- The name of the invasive alien species, and the name (if possible) and taxonomic group (plant, invertebrate, vertebrate, and microbe) of native species affected, as described in the document, and if the species was intensively used for multiple purposes by humans.
- The mechanism, magnitude (only for negative impacts) and direction of impacts on nature (**section 4.1.2**), at the local population level.
- The mechanism and direction of impacts on nature's contributions to people (**section 4.1.2**, **Box 4.3** and **Chapter 1**, **Box 1.12**). This doesn't include the magnitude of impacts on nature's contributions to people, as no standard methodology has been developed to date to assess it.
- The direction, magnitude (only for negative impacts) of impacts and affected constituents of good quality of life (**section 4.1.2**).
- The relation to Indigenous and local knowledge.

Authors did not collect data on the synergistic effects of other drivers of change in nature such as climate change (**Box 4.5**, in **section 4.3.1**), evolutionary aspects (**Box 4.8**, in **section 4.3.1.4**) or information on the interactions with other native or alien species (**Box 4.5**, in **section 4.3.1**).

**Box 4.3. Important terms and concepts used in this chapter**

**- Constituents of good quality of life** are material and immaterial assets; safety; health; social and cultural relationships; freedom of choice and action (**Chapter 1**, **Table 1.4**).

**- Impacts on ecosystem properties** are changes to (abiotic) ecosystem parameters e.g., soil variables, while it remains unknown how native species are affected by these changes (**section 4.1.1**).

[3] Data management report available at: https://doi.org/10.5281/zenodo.5766069

**- Impacts on good quality of life** (**Chapter 1**, **section 1.6.7.2**) can be positive or negative through changes in constituents of good quality of life; measured as changes in peoples' activities following the SEICAT approach (Bacher et al., 2018).

**- Impact magnitudes:**

- **Impact magnitudes on nature** follow the EICAT system from the IUCN (2020) namely impacts on performance of native individuals, population declines, local or global extinctions.

**- Impact magnitudes on good quality of life** are classified according to the SEICAT approach (Bacher et al., 2018) namely human activities are more difficult, some people stop certain activities, and activity is locally abandoned.

**- Mechanisms** include negative impacts on native species and follow the EICAT system from the IUCN (2020):

**- Competition** – the alien taxon competes with native taxa for resources (e.g., food, water, and space), leading to deleterious impact on native taxa.

**- Predation** – the alien taxon predates on native taxa, leading to deleterious impact on native taxa.

**- Hybridization** – the alien taxon hybridizes with native taxa, leading to deleterious impact on native taxa.

**- Transmission of disease** – the alien taxon transmits diseases (alien or native) to native taxa, leading to deleterious impact on native taxa.

**- Parasitism** – the alien taxon parasitizes native taxa, leading to deleterious impact on native taxa.

**- Poisoning/toxicity** – the alien taxon is toxic, or allergenic by ingestion, inhalation or contact, or allelopathic to plants, leading to deleterious impact on native taxa.

**- Bio-fouling or other direct physical disturbance** – the accumulation of individuals of the alien taxon on the surface of a native taxon (i.e., biofouling), or other direct physical disturbances not involved in a trophic interaction (e.g., trampling, rubbing, etc.) leads to deleterious impact on native taxa.

**- Grazing/herbivory/browsing** – grazing, herbivory or browsing by the alien taxon leads to deleterious impact on native taxa.

**- Chemical, physical, structural impact on ecosystem** – the alien taxon causes changes to the chemical characteristics of the native environment (e.g., pH; nutrient and/or water cycling), the physical characteristics of the native environment (e.g., disturbance or light regimes), or changes to the habitat structure (e.g., changes in architecture or complexity), leading to deleterious impact on native taxa.

**- Indirect impacts through interactions with other species** – the alien taxon interacts with other native or alien taxa (e.g., through any mechanism, including pollination, seed dispersal, apparent competition, mesopredator release), facilitating indirect deleterious impact on native taxa.

- **Nature's contributions to people** are composed of 18 categories (**Chapter 1**, **Box 1.12**; Díaz et al., 2018). Note that changes in nature's contributions to people do not always directly translate into positive or negative changes for people (e.g., if people do not use the increase in nature's contributions to people, then there is no actual contribution). Nature's contributions to people impacts are documented as positive or negative without assignment of magnitude, i.e., positive means an increase in nature's contributions to people, negative a decrease

- **Positive impacts** are assigned as positive when an entity profits from the change, i.e., a native species (impacts on nature) or humans (nature's contributions to people, good quality of life impacts).

**- Unit of analysis** have been adopted by this assessment to classify "habitats" (**Chapter 1**, **section 1.6.5)**

The database of impacts developed through this chapter contains data on 24,129 reports of impacts caused by 3,515 invasive alien species, representing 10.9 per cent of all alien species (ranging from 5.5 per cent to 22.4 per cent, depending on the taxonomic groups, **Table 4.1**). There were no studies of impacts for many alien species and the real percentages of invasive alien species causing impacts is likely to be higher than documented in this chapter. All numbers presented in this chapter are based on this single database compiled specifically for this chapter if not stated otherwise.

**Table 4.1.** Number of established alien species and invasive alien species identified in this assessment by taxonomic group
Data sources for the numbers of established alien species from different taxonomic groups: **Chapter 2**, **Table 2.3**). A subset of established alien species are known to cause adverse impacts; they are termed invasive alien species. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

| | Taxonomic group | | | | |
|---|---|---|---|---|---|
| | **Plants** | **Invertebrates** | **Vertebrates** | **Microbes** | **All taxa** |
| **Number of established alien species** | 19,365 | 8,282 | 3,242 | 1,257 | 32,146 |
| **Number of established alien species with documented impacts** | 1,061 | 1,852 | 461 | 141 | 3,515 |
| **Percentage of invasive alien species** | 5.5% | 22.4% | 14.2% | 11.2% | **10.9%** |

Of the 3,515 invasive alien species that were found to cause impacts, 1,673 (48 per cent) cause impacts on nature, 1,530 (44 per cent) on nature's contributions to people, and 1,032 (29 per cent) on good quality of life. Invasive alien species frequently cause more than one type of impact: 556 invasive alien species (16 per cent) cause impacts on both nature and nature's contributions to people, 235 species (7 per cent) on both nature and good quality of life. About 5 per cent of all invasive alien species cause impacts on all three categories.

There are similar numbers of impacts documented from the Americas (8,163 reports), Europe and Central Asia (7,481), and Asia-Pacific (6,016), but considerably fewer reports from Africa (1,725) (**Figure 4.2**). Of all the documented impacts, 4,679 are from islands, and 3,324 from protected areas. Most documented impacts are from the terrestrial realm (18,011, 74.6 per cent) with considerably fewer from aquatic realms (inland waters: 3,299, 13.7 per cent; marine: 2,352, 9.7 percent); 467 of the documented impacts were from studies that did not specify the realm (**Figure 4.2**). Invasive alien species have been documented to cause impacts across all units of analysis, but most reports are from temperate and boreal forests and woodlands, inland waters and cultivated areas (including cropping, intensive livestock farming; **Table 4.2**). There are very few documented impacts from the open ocean, and no reports from the deep sea and the cryosphere were found. Twenty per cent of all impacts are reported from islands.

The most frequently documented impacts of invasive alien species are caused by plants (10,091 documented impacts), followed by invertebrates (8,180 documented impacts) and vertebrates (5,182 documented impacts), with invasive alien microbes having the lowest number of impact reports (676 documented impacts) (**Figure 4.2**). These include all types of impacts (nature, nature's contributions to people, good quality of life) and all directions (positive, negative, and those that cannot be assigned a direction). Of the 13,898 documented impacts of invasive alien species on ecosystems properties, most affected native plants (6,376 documented impacts), followed by native invertebrates (4,629 documented impacts) and vertebrates (3,576 documented impacts), with impacts on native microbes being considerably less often documented (312).

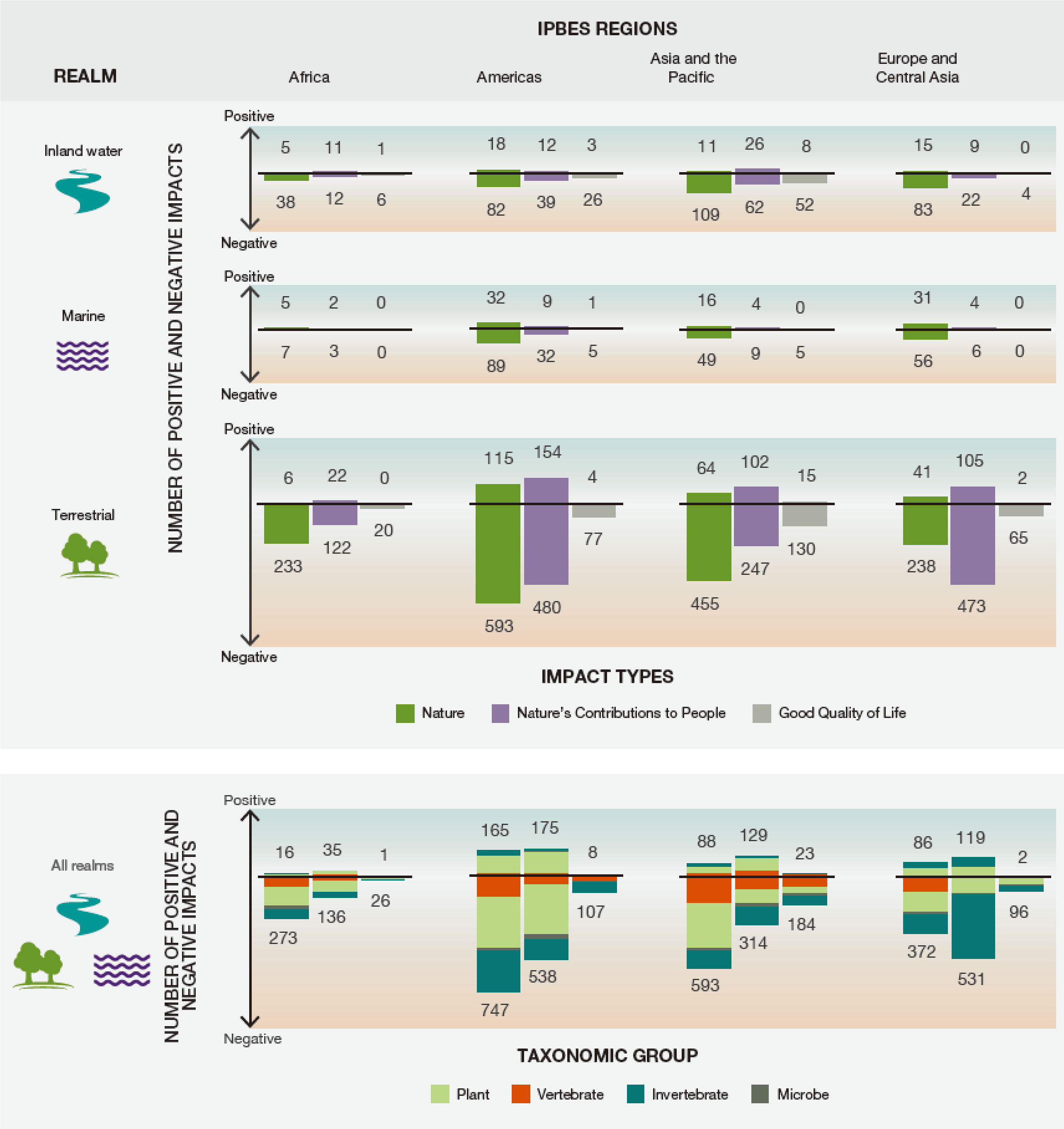


**Figure 4.2.** Number of invasive alien species with documented negative and positive impacts on nature, nature's contribution to people and good quality of life, by taxonomic group, realm and IPBES region. Numbers and bars above indicate invasive alien species with positive impacts, numbers and bars below the x axes species with negative impacts. Positive and negative stacked bar charts do not imply that positive and negative impacts can be summed. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

**Table 4.2.** Number of documented impacts across IPBES units of analysis

A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

| IPBES units of analysis | Number of impact records |
|---|---|
| Tropical and subtropical dry and humid forests | 2,664 |
| Temperate and boreal forests and woodlands | 3,849 |
| Mediterranean forests, woodlands and scrub | 1,248 |
| Tundra and high mountain habitats | 205 |
| Tropical and subtropical savannas and grasslands | 1,106 |
| Temperate grasslands | 2,147 |
| Deserts and xeric shrublands | 579 |
| Urban/semi-urban | 1,480 |
| Cultivated areas (incl. cropping, intensive livestock farming etc.) | 3,032 |
| Aquaculture areas | 144 |
| Wetlands – peatlands, mires, bogs | 728 |
| Inland surface waters and water bodies/freshwater | 3,107 |
| Shelf ecosystems (neritic and intertidal/littoral zone) | 2,295 |
| Open ocean pelagic systems (euphotic zone) | 7 |
| Coastal areas intensively used for multiple purposes by humans | 649 |
| Cryosphere | - |
| Deep-sea | - |

# 4.3. Impacts of invasive alien species on nature

## 4.3.1. General patterns

Invasive alien species impact nature globally, and the majority of documented impacts are negative. This chapter documents more than 15,000 impacts on nature caused by 3,515 invasive alien species (**section 4.2**). Only a subset of these can be classified with a direction as being either negative, neutral or positive for native species (**section 4.1.2**). Of all the documented impacts with an assigned direction, 85 per cent (10,822) can be considered as negative impacts (caused by 1,623 species), and only 15 per cent (1,976) can be considered as positive impacts (caused by 361 species). Impact on ecosystem properties caused by 1,560 invasive alien species cannot be classified as either positive or negative impacts.

The vast majority of impacts were documented after the year 2000 (**Figure 4.3**), which is likely to be a consequence of an increase in impacts correlated with the increase in number and occurrence of invasive alien species globally (**Chapter 2**, **section 2.2.1**), but is also due to an increase in research on the impact of invasive alien species. Negative impacts on nature have been documented since the beginning of the twentieth century with an almost exponential increase through time, while positive impacts of invasive alien species only started being documented in the 1970s (**Figure 4.3**).

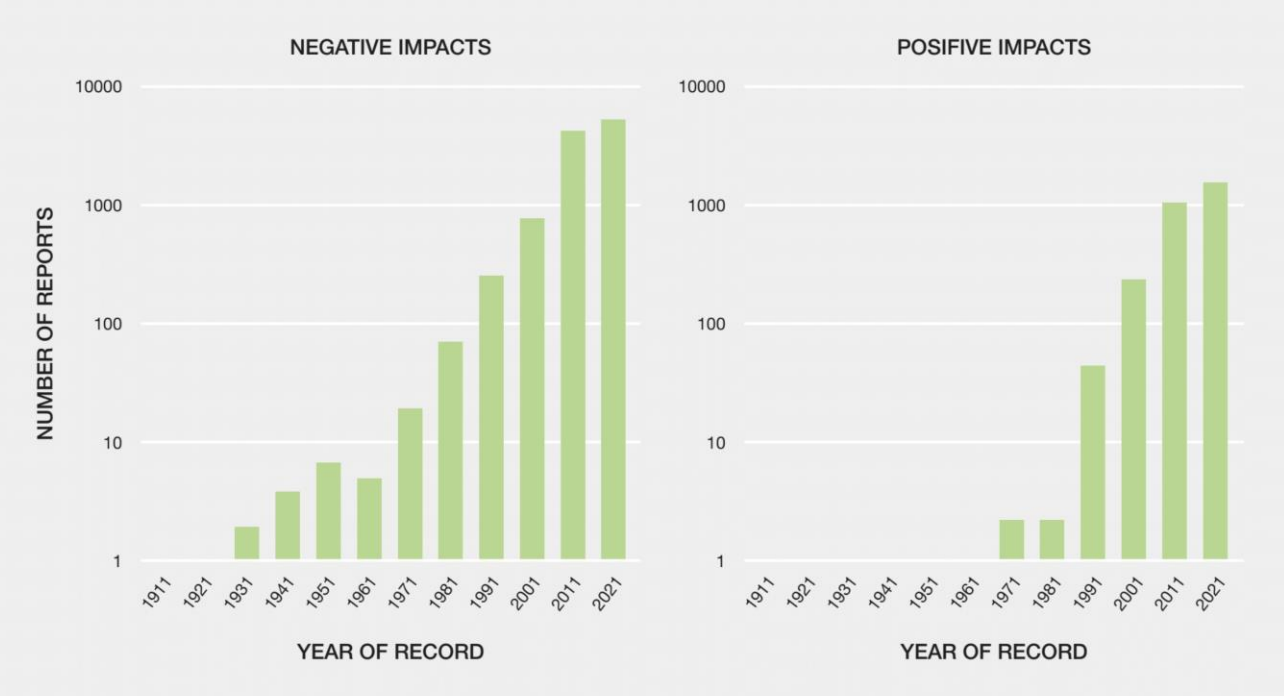


**Figure 4.3.** Number of reported negative and positive impacts (y axes) on nature over time (x axis), from published literature since 1900 (note the logarithmic scale). A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

**Invasive alien species most often documented causing impacts on nature**

Invasive alien species with most records of negative impacts on nature include many vertebrates, e.g., terrestrial mammals such as *Rattus rattus* (black rat), *Rattus exulans* (Pacific rat), *Felis catus* (cat), and *Vulpes vulpes* (red fox); *Rhinella marina* (cane toad); or marine and inland waters fishes such as *Pterois volitans* (red lionfish) and *Cyprinus carpio* (common carp). The ten most-often documented invasive alien species with negative impacts on nature include several ant species such as *Solenopsis invicta* (red imported fire ant), *Linepithema humile* (Argentine ant), and *Anoplolepis* *gracilipes* (yellow crazy ant); and *Procambarus clarkii* (red swamp crayfish). Examples of plants with many documented negative impacts on nature include *Reynoutria japonica* (Japanese knotweed) and *Lantana camara* (lantana).

Most positive impacts on nature are caused by plants and invertebrates. Terrestrial plants, such as *Solidago gigantea* (giant goldenrod), *Reynoutria japonica* (Japanese knotweed), or *Carpobrotus* spp. (iceplant), and trees like *Acacia longifolia* (golden wattle) are abundant nectar sources for many native insect species. Marine species such as *Caulerpa cylindracea* (green algae) provide habitat for native species. Aquatic invertebrates such as *Magallana gigas* (Pacific oyster), *Dreissena* spp. (zebra and quagga mussels), *Ficopomatus enigmaticus* (tubeworm), or *Didemnum vexillum* (carpet seas quirt) also impact positively nature by creating habitat, and sometimes providing food, for native species. Although there are no vertebrates among the top ten invasive alien species with most records of positive impacts on nature, those with the most frequent documented positive impacts are *Neogobius melanostomus* (round goby), which provides food for native species (Hempel et al., 2016; Rakauskas et al., 2020), and *Rhinella marina* (cane toad), which indirectly favors native medium-sized predators by reducing populations of their competitors and/or top predators (Brown et al., 2011; Doody et al., 2013).

A total of 280 (8 per cent) invasive alien species have been documented to cause both negative and positive impacts on nature (**section 4.1.2**). Among these are many of the species that most often have been documented causing negative impacts, such as *Dreissena* spp. (zebra and quagga mussels), *Reynoutria japonica* (Japanese knotweed), or *Rhinella marina* (cane toad).

**Local extinctions**

Some invasive alien species cause local extinctions of native populations. Six per cent (218 species) of all invasive alien species with documented impacts have caused a total of 1215 local extinctions of native populations. Local extinctions have occurred in all realms, but most extinctions have been documented in the terrestrial (62.1 per cent) realm, followed by the marine (23.2 per cent) and inland waters (14.5 per cent) realms (**Table 4.3**). Overall, invasive alien animals have caused the most local extinctions of native species (vertebrates 51.0 per cent, invertebrates 32.5 per cent) in the terrestrial realm; whereas invasive alien plant species (15.3 per cent) and microbes (1.2 per cent) have caused fewer local extinctions (**Table 4.3**). In contrast, in the marine realm, invasive alien invertebrates (47.5 per cent) and plants (34.8 per cent) are more often documented to be the cause for local extinctions than invasive alien vertebrates (17.0 per cent; **Table 4.3**).

Invasive alien vertebrates dominate the list of species causing local extinctions, e.g., *Felis catus* (cat), *Rattus rattus* (black rat), *Rattus exulans* (Pacific rat), *Vulpes vulpes* (red fox), and *Capra hircus* (goats), but also the marine fish *Pterois volitans* (red lionfish). Ants also often lead to local extinctions, particularly species such as *Linepithema humile* (Argentine ant), *Anoplolepis gracilipes* (yellow crazy ant), and *Solenopsis invicta* (red imported fire ant). Plants that frequently lead to local extinctions are *Caulerpa cylindracea* (green algae) and *Pontederia crassipes* (water hyacinth). Microbes are less frequently implicated in local extinctions; pathogens that have caused local extinctions are *Batrachochytrium dendrobatidis* (chytrid fungus), *Austropuccinia psidii* (myrtle rust), *Ceratocystis platani* (canker stain of plane), *Cryphonectria parasitica* (blight of chestnut), the *Haplosporidium nelsoni* (MSX oyster pathogen), and *Morator aetatulas* (sacbrood virus) that affects honeybee larvae.

**Table 4.3.** Number of local extinctions caused by invasive alien species by taxonomic group and realm

Number of documented local extinctions caused by invasive alien species for invertebrates, microbes, plants and vertebrates in different realms. Two local extinctions (plant, microbe) could not be assigned to a realm. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

| | **Number of local extinctions in the marine realm** | **Number of local extinctions in the terrestrial realm** | **Number of local extinctions in the inland waters realm** | **Number of local extinctions in all realms** |
|---|---|---|---|---|
| *Local extinctions caused by invasive alien plants* | 98 | 53 | 35 | 187 |
| *Local extinctions caused by invasive alien invertebrates* | 134 | 210 | 50 | 394 |
| *Local extinctions caused by invasive alien vertebrates* | 48 | 480 | 91 | 619 |
| *Local extinctions caused by invasive alien microbes* | 2 | 12 | 0 | 15 |
| **All taxa** | **282** | **755** | **176** | **1,215** |

**Global extinctions**

Where invasive alien species caused global extinctions (**Box 4.4**), the impacted native species often had a restricted spatial distribution with immutable borders. Thus, species endemic to islands, mountain ranges, or isolated lakes and river systems seem to be particularly at risk of global extinction caused by invasive alien species. Examples include *Boiga irregularis* (brown tree snake), which caused the local extinction and serious reduction of populations of most of the Guam's resident 25 bird species (Wiles et al., 2003), leading to the global extinction of *Myiagra freycineti* (Guam flycatcher). Several global extinctions were attributed to the invasive alien *Euglandina rosea* (rosy predator snail), a predatory snail native to Central America and southern United States of America, introduced to many pacific islands to control *Lissachatina fulica* (giant African land snail) (Gerlach et al., 2021). This terrestrial predatory snail led to the global extinction of several, mostly tree-inhabiting island-endemic snails of the genus *Partula* (Coote & Loève, 2003). The invasive alien *Rattus rattus* (black rat) has been documented as the only cause of the global extinctions of *Nesoryzomys darwini* and *Nesoryzomys indefessus* (rice rats) endemic to the protected areas of the Galapagos Islands (Tirira & Weksler, 2017, 2019).

**Box 4.4. Global extinctions caused by invasive alien species**

Invasive alien species have a range of impacts on nature which can ultimately lead to the global extinction of native species. The IUCN Red List synthesized information about species extinctions as well as their associated threats, which provides a basis to study the impact of invasive alien species in terms of extinctions. The IUCN Red List documented 327 animal and plant species as globally extinct or extinct in the wild with invasive alien species mentioned as one of the causes of extinctions, with an additional 205 species that are considered possibly extinct (average 50 years since the last specimen was seen). Invasive alien species are the only cause attributed to 16 per cent of all species extinctions documented in that database (K. G. Smith, 2020). Invasive alien species are also categorized as a significant contributing factor (i.e., having caused significant decline to the majority of the species' ranges) in nearly 60 per cent of extinctions, while in the remaining cases the role of invasive alien species as driver of extinctions is unknown and most likely minor compared to other drivers of change. By focusing on species extinctions in which the primary cause has been identified, invasive alien species are by far the most frequently mentioned driver. Note that most of the species that have gone extinct due to invasive alien species were also harmed by wildlife exploitation and/or cultivation and those threats are likely to act in combination on insular species (Leclerc et al., 2018).

Among the extinctions in which invasive alien species are categorized as a significant cause (n=186), the overwhelming majority occurred on oceanic or continental islands (90 per cent). The risk of extinctions was greater on islands presumably because the species had reduced geographical range (**Glossary**), small population size, and reduced pressure from native predators compared to continental species (J. G. Cox & Lima, 2006; **Boxes 4.6**, **4.7**). For instance, naïve island birds, that have never encountered mammalian predators such as rodents and *Felis catus* (cat), are particularly vulnerable (Dueñas et al., 2021; Medina et al., 2011; Whitworth et al., 2013; **Figure 4.4**). Extinction hotspots where invasive alien species are documented as the main cause are located in the Asia-Pacific region (73 per cent), followed by the Americas (15 per cent) and Africa (14 per cent). Vertebrates (62.4 per cent), invertebrates (26.3 per cent) and plants (11.3 per cent) suffered most extinctions as a consequence of invasive alien species, with birds (74 species) most vulnerable. (H. P. Jones et al., 2008; Spatz et al., 2014; Szabo et al., 2012). This threat continues to the present (Butchart, 2008; Dueñas et al., 2021).

**Figure 4.4.** Examples of extinct birds due to invasive alien cats on islands. On islands, *Felis catus* (cat) has caused the extinction of *Anthornis melanocephala* (Chatham bellbird; left), *Cyanoramphus novaezelandiae erythrotis* (Macquarie Island parakeet; middle), and *Microgoura meeki* (Choiseul

pigeon; right). Photo credits: Lynx Edicions, Jan Wilczur (left); Norman Arlott (middle); John Cox (right) – Copyright.

The number of mollusc extinctions documented by the IUCN Red List may underestimate the role of invasive alien species. A recent re-evaluation attributed at least 134 inland waters species extinctions exclusively to the introduction of the notorious predatory alien snail, *Euglandina rosea* (rosy predator snail; Régnier et al., 2009). This species was intentionally introduced in the 1950s to the 1970s as a biological control agent for *Lissachatina fulica* (giant African land snail) in many Pacific islands. It also feeds on other snails and consequently a third of the species within the snail family Partulidae (Gastropoda) in the Pacific Islands are now extinct, the rest being at risk of extinction (Gerlach, 2016). Inland waters fish are also particularly affected by invasive alien species, with 8 native fish species documented as extinct worldwide due predominantly to interactions with various invasive alien fish and an additional 37 fish extinctions attributed to invasive alien species as one of several causes. Note that the same taxa are affected (i.e., birds, gastropods, fishes, mammals and angiosperms) when considering all the extinct species where invasive alien species are cited as one of the causes, but not necessarily the main one (**Figure 4.5**).

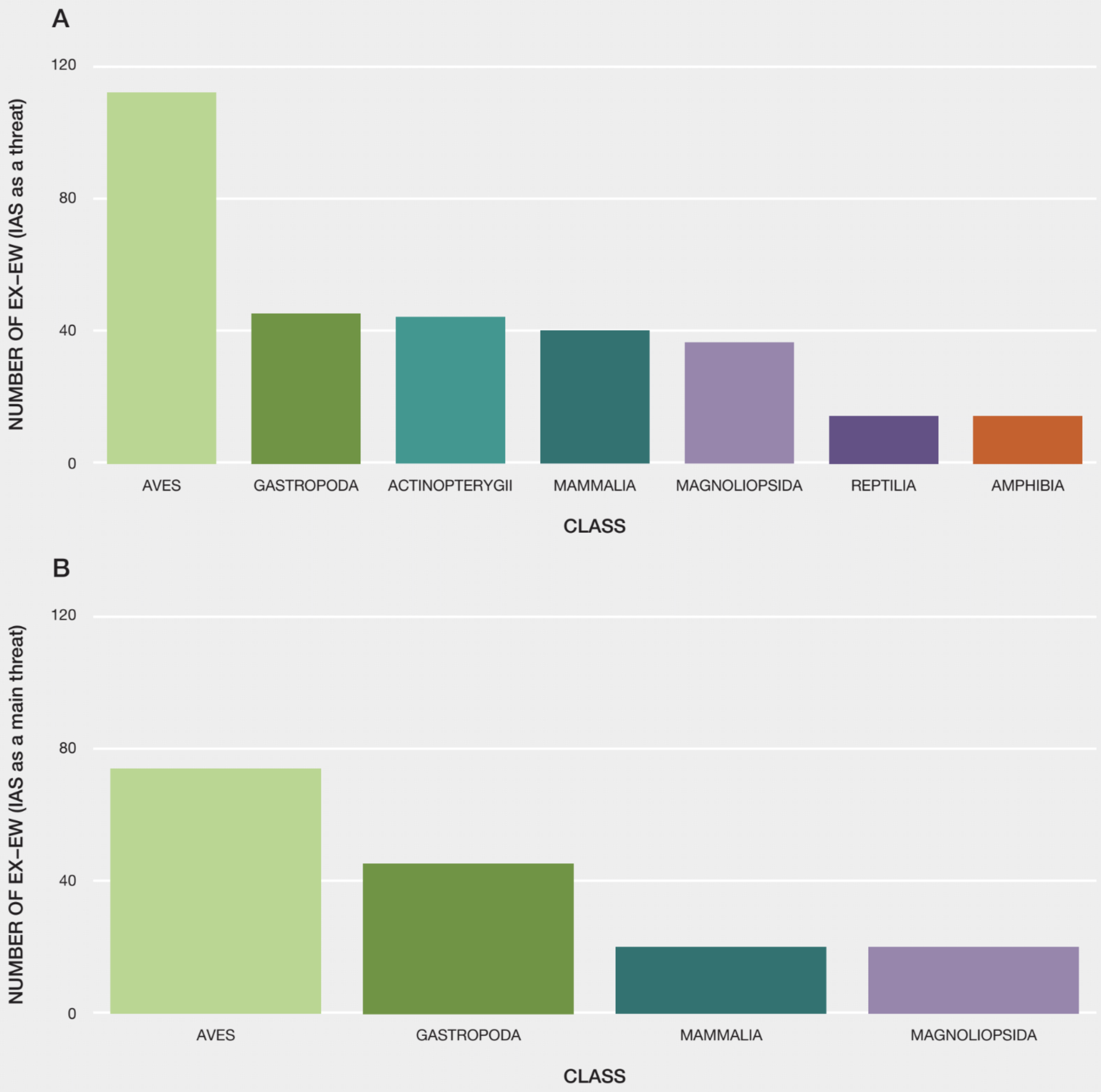


**Figure 4.5.** Number of extinct species, including extinct in the wild (EX-EW), by classes. These bar plots only show classes represented by at least 10 extinct species, with A) all extinct species

(EX-EW) where invasive alien species (IAS) are cited as one of several causes (but not necessarily the main one) and B) all extinct species (EX-EW) where invasive alien species (IAS) are considered as the main cause of extinction. A data management report is available at: https://doi.org/10.5281/zenodo.5762737

At least 44 invasive alien species are implicated in the 186 extinctions documented by the IUCN as caused by invasive alien species, with rodents and *Felis catus* (cat) involved in more than a third of all extinctions. The large majority of the invasive alien species are represented by alien mammals that were responsible for the extinctions of native birds and mammals, while most of the amphibians are threatened by *Batrachochytrium dendrobatidis* (chytrid fungus; Pounds et al., 2006).

Despite the fact that the IUCN Red List is recognized as the world's most comprehensive information source on the global conservation status of species, it should be emphasized that the attribution of factors driving extinctions relies on evidence from published literature (including peer review) in addition to expert opinion and thus is subject to data gaps in observations and to some level of uncertainty (IUCN, 2022; Salafsky et al., 2008). The scientific literature frequently lacks specific information on already extinct species. This is particularly true for extinctions that occurred before the 1950s for which clear information is scarce (**Figure 4.6**; see also Sayol et al., 2020). A recent systematic review, of manipulative experimental or comparative observational (before-after; control-invaded plots; BACI design; Kumschick et al., 2015), on current extinction threat confirmed findings from the IUCN Red List on the strong impact of invasive alien species on threatened species (Dueñas et al., 2021). Yet, the most prevalent threats across near-threatened and threatened species worldwide are overexploitation and agricultural activity (Maxwell et al., 2016). It is thus crucial to emphasize that the number of extinctions or the number of species at risk of extinction are not the only reliable metrics to study the impacts of invasive alien species. The IPBES Global Assessment of Biodiversity and Ecosystem Services synthesized 11 biodiversity indicators including local species richness, mean body length and the IUCN Red List indices (Purvis et al., 2019). Using those indices, the relative importance of invasive alien species may vary across ecosystems, taxa, and measure of biodiversity (Bellard et al., 2022). As a consequence, the contribution of invasive alien species to explain the current biodiversity crisis should be carefully discussed considering the specific context, taxa, and metrics to avoid oversimplifications.

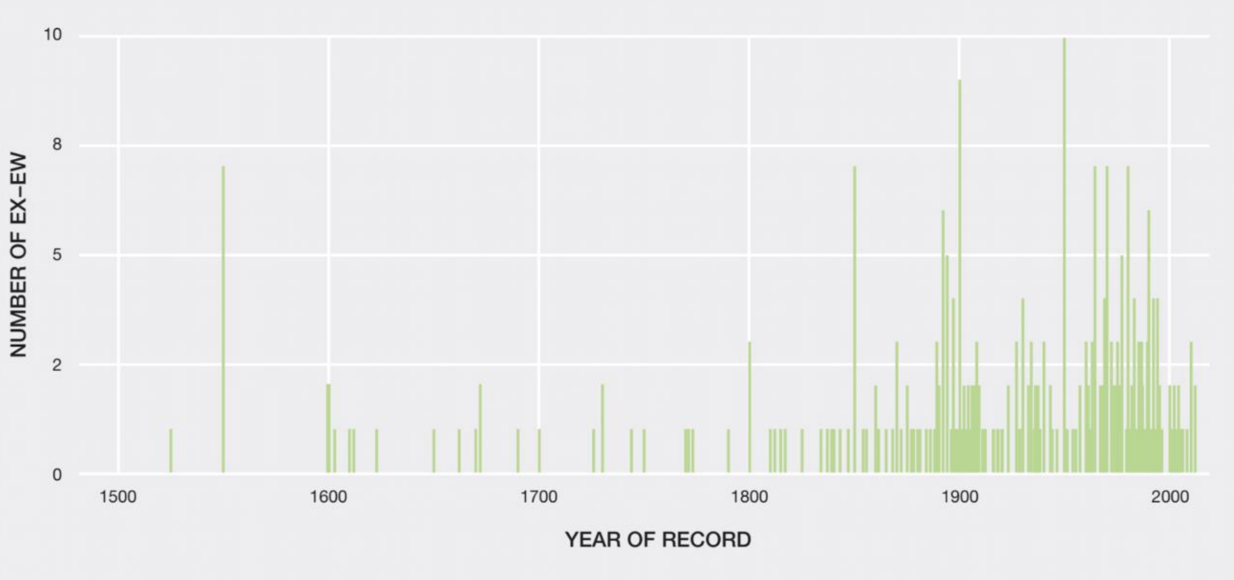

**Figure 4.6.** Number of records of species extinct or extinct in the wild (EX-EW) since 1500, with their last seen date indicated. Information was available for 276 extinct species. Data source: IUCN (2021).

Global extinctions due to invasive alien species are not restricted to islands. *Batrachochytrium dendrobatidis* (chytrid fungus) is a pathogen of a wide range of amphibians and can be found in the Americas, Africa, Western Europe, South-East Asia and Australia (M. C. Fisher & Garner, 2020). Its origin is still disputed, but it has been widely transported and introduced by humans, initially probably with the global use of *Xenopus laevis* (African clawed frog) for medicinal purposes starting in the 1950s (Kay & Peng, 1992). *Batrachochytrium dendrobatidis* has contributed to the severe global decline of amphibians generally (M. C. Fisher & Garner, 2020), and has caused the global extinction of several native harlequin toads of the genus *Atelopus* from the mountains of Central America (La Marca et al., 2005), most likely because climate warming increased the habitat suitability for the pathogen (Pounds et al., 2006; **Box 4.5**). Global extinctions due to invasive alien species have also occurred in aquatic realms. As an example, *Lates niloticus* (Nile perch) was introduced from its native range in Lake Albert to Lake Victoria to improve local fisheries but led to the global extinction of many cichlid fish species endemic to Lake Victoria (Goudswaard et al., 2008). It remains controversial whether the introduction of *Lates niloticus* has profited local fishermen (**Box 4.10**).

No global extinctions due to invasive alien species were documented in the marine realm; this might be partly because immutable dispersal borders are less frequent in the marine realm. Yet, one should also take into consideration that it is far more difficult to document impacts and their causality in marine environments due to accessibility challenges (Ojaveer et al., 2015).

**Box 4.5. Invasive alien species impacts can worsen when interacting with other drivers of change**

Invasive alien species occur in interaction with other major drivers of biodiversity change, such as climate change, land- and sea-use change, pollution and over exploitation of natural resources (IPBES, 2019a; **Chapter 3**, **section 3.5**). Interactions may be classified as additive, antagonistic or synergistic with examples of all outcomes evident from studies on the interactions between invasive alien species and other drivers. Research on multiple drivers of biodiversity change is challenging, with drivers operating at different temporal and spatial scales (Bonebrake et al., 2019). Additionally, the interdisciplinary skills and resources required to study multiple drivers may not be available in all regions of the world. A recent metanalysis, assessing 458 cases from 95 published studies (with 74 of these being laboratory or mesocosm experiments) on individual and combined effects of drivers of change on invasive alien species, demonstrated that synergistic interactions were documented for more than 25 per cent of the studies (Lopez et al., 2022). However, it is notable that in most cases the impacts of invasive alien species were not exacerbated by the other drivers, but the combined impacts of the other drivers with invasive alien species were typically no worse than the impacts from invasive alien species alone. Documented synergistic interactions mostly lead to the deterioration of ecosystems (Lopez et al., 2022). There are several studies that have provided evidence on the synergistic effects of invasive alien species and other drivers of biodiversity change, here we highlight four examples of these phenomena (**Figure 4.7**):

**Climate change and invasive alien plants increase fire frequency and intensity**
In a scenario of climate change, where vast areas of the Earth will not only be warmer but drier, and the number of lightning events is expected to increase, invasive alien plants may worsen the situation by adding additional highly flammable fuel (Aslan & Dickson, 2020; Turbelin & Catford, 2021). For example, *Pinus* spp. (pine) invading grasslands and forests of South America may increase fire intensity and frequency (Cóbar-Carranza et al., 2014; Paritsis et al., 2018; **Chapter 1**,

**Box 1.4**). Similar effects have been documented in the South African fynbos (O'Connor & van Wilgen, 2020).

**Climate change and alien mosquitoes threaten the health of humans and animals**
For some vector-borne diseases, climate change may increase the range and the density of the invasive alien species vector (**Glossary**) with profound implications for human health. For example, *Anopheles* spp. (mosquitoes) that carry malaria have been documented to advance into higher latitudes of the Americas and Europe (Tjaden et al., 2018; Brugueras et al., 2020). Climate change has also been implicated in the rapid decline of amphibians as it interacts with the invasive pathogenic *Batrachochytrium dendrobatidis* (chytrid fungus), which may explain population reductions and even extinctions (J. M. Cohen et al., 2019).

**Pollution and invasive organisms can transform water bodies**
Change in nutrient levels due to pollution can increase populations of aquatic invasive alien species in inland waters and marine ecosystems reducing native species diversity (Crooks et al., 2011). Some aquatic invasive alien plants, such as *Pontederia crassipes* (water hyacinth), thrive in highly polluted eutrophicated habitats, worsening the consequences for local fisheries, infrastructure and transport (Villamagna & Murphy, 2010; Kleinschroth et al., 2021).

**Hunting and invasive alien vertebrates can bring populations of native species in islands or forests to extinction (steep population reductions)**
A combined effect of hunting and invasive alien predators may cause faster local reductions in populations of endangered vertebrates such as birds, amphibians and mammals (e.g., New Zealand birds in Innes et al., 2010). Furthermore, hunting can also be a source of new introductions of game animals (Carpio et al., 2017), but in some cases, hunting may also be an effective tool to control invasive alien species (Jean Desbiez et al., 2011).

**Interactions amongst three or more drivers including invasive alien species**
Conceptualization and quantification of impacts of the interaction of three or more drivers is a highly complicated endeavour (e.g., birds in Doherty et al., 2015; bats in Frick et al., 2020; deer and earthworms in Frelich et al., 2006). However, evidence suggests that measures including research could address these complex interactions to concurrently reduce the threats of multiple drivers on biodiversity. Evidence suggests that while invasive alien species can exacerbate the impacts of other drivers of biodiversity change, the impacts of invasive alien species are generally no worse when acting in combination with other drivers of change such as climate change, pollution, over exploitation or land and sea use change (Lopez et al., 2022). Indeed, managing biological invasions locally contributes to reducing the threat of multiple drivers of change (**Chapter 3**, **section 3.5**; **Chapter 5**, **section 5.6.1.3**).

**Figure 4.7.** Species affected by multiple drivers of change, including invasive alien species. *Atelopus* toads threatened by extinction due to *Batrachochytrium dendrobatidis* (chytrid fungus)

which grows better due to climate change; water hyacinth covering large parts of eutrophic tropical lakes due to increased nitrogen pollution. Photo credits: Brian Gratwicke, WM Commons – CC BY 2.0 (left) / NickLubushko, WM Commons – CC BY 4.0 (right).

**Case study: Avian botulism, a probable synergistic impact of alien species and climate warming in the North American Great Lakes**

In the North American Great Lakes, several alien species are considered to contribute to recurring mass die-offs of waterfowl by transmitting botulin toxin. Filtration activities of Ponto-Caspian dreissenid mussels (*Dreissena polymorpha* (zebra mussel) and *Dreissena rostriformis bugensis* (quagga mussel) introduced to the Great Lakes in the 1980s) increase light transparency in the water and consequently promote excessive summer growth of macrophytes and benthic macroalgae (Vanderploeg et al., 2002). Later in the summer, the decomposing biomass of this vegetation, combined with elevated water temperatures resulting from climate change-generated hypoxic conditions, favouring outbreaks of a rare cryptogenic (**Glossary**) strain of botulism bacteria, *Clostridium botulinum* Type-E (Chun et al., 2013). The bacteria are then filtered by dreissenid mussels, which concentrate the toxic cells in their tissues. The mussels and other contaminated benthic invertebrates subsequently transfer the toxin to *Neogobius melanostomus* (round goby), a benthic predatory Ponto-Caspian fish introduced to the Great Lakes region, that is itself a common prey item for piscivorous native waterfowl such as loons and gulls (Essian et al., 2016; **Figure 4.8**). Thus, the combination of alien species and increased temperatures through climate change promotes the proliferation and transfer of botulinum toxin to higher trophic levels, creating a new contaminant pathway (**Glossary**) that has caused the mortality of tens of thousands of waterfowls in the Great Lakes nearly every year over the past two decades (Essian et al., 2016; Yule et al., 2006).

**Figure 4.8.** Dead waterbirds on a beach on Georgian Bay, Lake Huron, October 2011. Waterbirds mass die-off is attributed to botulism, which is considered to proliferate due to the presence of invasive alien species. Photo credit: Rogers Media Inc. – CC BY 4.0.

**Reduction of population sizes**

Many invasive alien species that are not documented to cause local extinctions can still reduce the population size of native species. The database of impacts developed through this chapter shows that 21.8 per cent (766) of the studied invasive alien species have caused a total of 4,282 local population declines in native species, which represents 36.6 per cent of the documented negative impacts on nature. While many invasive alien plants have not been documented causing local extinctions, they frequently cause declines in native species populations. Such invasive alien plants include the terrestrial forbs *Reynoutria japonica* (Japanese knotweed), *Impatiens glandulifera*

(Himalayan balsam), *Carpobrotus* spp. (iceplant), *Eragrostis lehmanniana* (Lehmann lovegrass), or *Acacia longifolia* (golden wattle) and *Robinia pseudoacacia* (black locust). Other invasive alien species that have been documented as frequently causing at least local population declines are *Acridotheres tristis* (common myna) or *Bubalus bubalis* (Asian water buffalo), and *Phytophthora ramorum* (sudden oak death).

Invasive alien plants have the highest number of species causing impacts on nature, followed by invertebrates and vertebrates. Comparatively few invasive alien microbes are documented causing impacts on nature (**Figure 4.9A**). By contrast, more invasive alien animals (vertebrates and invertebrates) cause high magnitude impacts, i.e., local extinctions, both in terms of the number of species causing impacts (**Figure 4.9A**) and the number of reports (**Figure 4.9B**). Local extinctions are less frequently caused by plants, and microbes are rarely documented to have caused local extinctions. Invasive alien plants also have the highest number of species causing impacts on ecosystem properties, population declines and reductions in individual performance of native species.

Impacts on native species by invasive alien vertebrates are more frequent than impacts on ecosystem properties (**Figure 4.9A**), while, in contrast, invasive alien invertebrates more frequently cause negative impacts on ecosystem properties (e.g., abiotic soil or water characteristics; **Box 4.3**) than on native species. Invasive alien plants and microbes have similar frequencies of negative impacts on ecosystem properties and native species.

Invasive alien plants have the highest numbers of species (both in absolute numbers and percentages; **Figure 4.9A**) and reports (**Figure 4.9B**) of positive impacts on nature globally. There are more invasive alien invertebrates than vertebrates causing positive impacts, but microbe species are very rarely documented in this respect.

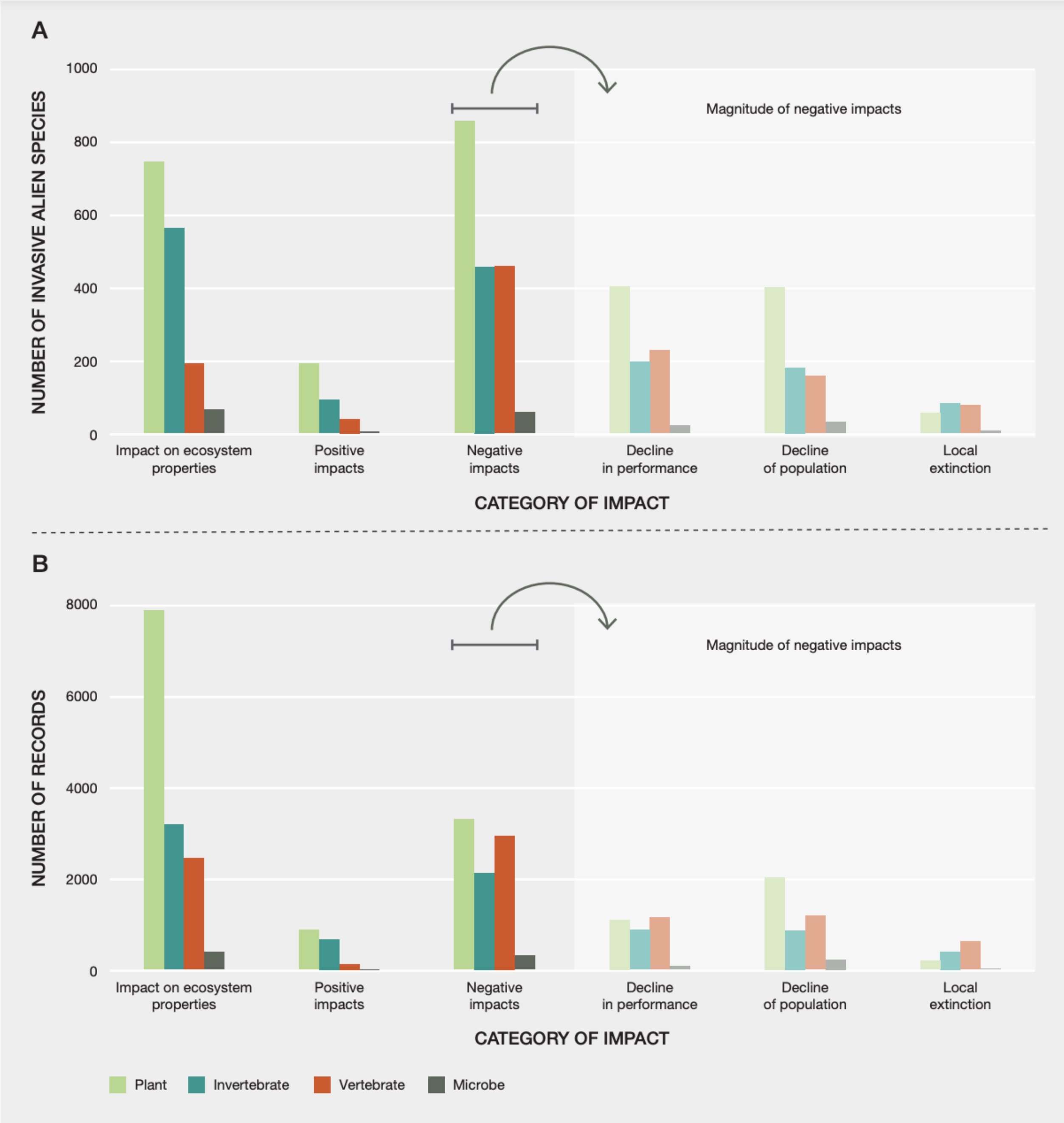


**Figure 4.9.** Number of A) invasive alien species causing impacts on nature and B) number of impact records by direction, magnitude and taxonomic group. Negative and positive impacts relate to the consequences for native species, while impacts on ecosystem properties are not assigned a direction. Negative impacts are subdivided for each invasive alien species into the maximum documented negative impact on a native species globally (lighter box on the right). Note that the same invasive alien species could have a maximum negative impact on a native species, impacts on ecosystem properties and positive impacts on native species. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

### 4.3.1.1. Islands versus mainland

Islands, particularly smaller sized and more isolated islands, with higher rates of endemism, suffered greater impacts on nature than mainland regions. Following the introduction of various suites of alien predators and competitors through millennia of human settlement, the severity and rate of extinction has varied due to geomorphology, composition of the native biota and that of the introduced invasive alien species, and lifestyle and technology of human settlers (e.g., hunting-gatherering, husbandry, agriculture) (Wood et al., 2017). Smaller islands which tend to support smaller native populations in easily accessible habitats, are more susceptible to impacts from invasive alien species through predation or habitat loss, leading to greater rates of extinction and other negative impacts (Duncan & Blackburn, 2007).

Impacts on islands represent 4,820 (19.9 per cent) of the total number of impacts on nature documented in published studies (**Boxes 4.6** and **4.7**). Negative impacts on native species on islands are far more frequent (40.5 per cent) than positive impacts (4.5 per cent; **Figure 4.10**).

There is no clear difference in the proportion of negative and positive impacts and impacts on ecosystem properties between island and non-island locations (**Figure 4.10**). However, negative impacts of high magnitude, i.e., local extinctions, are more frequently documented from islands than from non-island locations (9.2 per cent vs. 4.0 per cent; **Figure 4.10**).

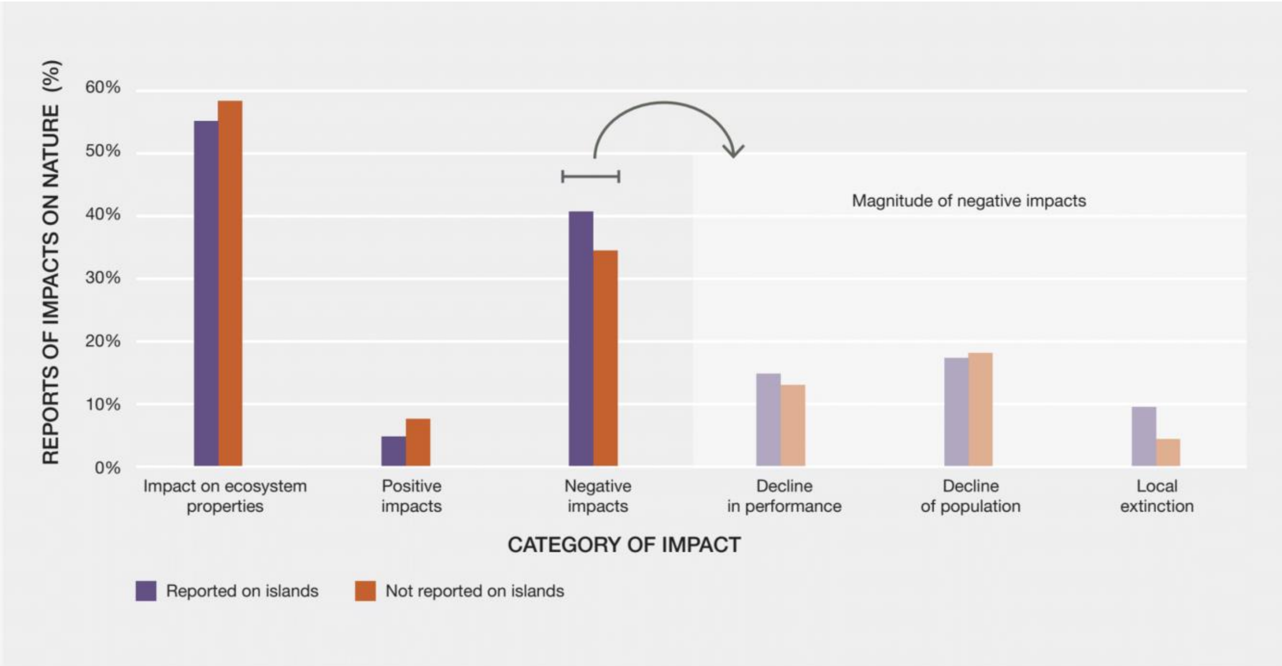


**Figure 4.10.** Percentage of reports of impacts on nature on islands vs. locations that were either not on an island (mainland) or unknown. For each of the three impact categories, ecosystem properties, positive and negative impacts, the percentages sum to 1. Negative impacts are split into their impact magnitudes in the shaded box on the right-hand side. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

On islands, globally, 87 invasive alien species have caused 445 local extinctions. They are most often caused by mammals, such as *Rattus* spp. (rats), *Capra hircus* (goats), *Mus musculus* (house mouse), *Felis catus* (cat), but also other vertebrates such as *Anas platyrhynchos* (mallard) and *Boiga irregularis* (brown tree snake). Ants have also often led to local extinctions on islands, particularly from species such as *Anoplolepis gracilipes* (yellow crazy ant), *Wasmannia auropunctata* (little fire ant), *Linepithema humile* (Argentine ant), and *Pheidole megacephala* (big-headed ant). Invasive alien plants are much less often causing local extinctions on islands, but there are some reports, as for example from *Vachellia nilotica* (gum arabic tree).

**Box 4.6. Hawaiian extinctions – the birds and the bees and much else**

"The islands now contain more endangered species per square mile than anywhere else in the world" (Cabin, 2013).

Hawaii's isolation in remote Oceania resulted in a unique terrestrial biota, distinguished by the diversity of endemic forms derived from a small number of ancestral immigrations (Wagner et al., 1990; Imada, 2012). Zooarchaeological and archaeobotanical studies reveal that the arrival of humans about 1500 years ago induced catastrophic ecosystem changes (Allen, 1984, 1989; Steadman, 1995). The Polynesian settlers transported their domesticates, including dogs, pigs, chickens, and the synanthropic *Rattus exulans* (Pacific rat; Crabtree, 2016). Their direct and indirect impacts, through habitat loss, fragmentation, and predation by the introduced mammals, caused losses of many species, and are continuing into the present (Vitousek & Walker, 1989; G. W. Cox, 1999; Staples et al., 2000; Staples & Cowie, 2001; Vorsino et al., 2014; MacLennan, 2017). Pollen analysis reveals that following Polynesian settlement Hawaii's lowland forests were reduced to a landscape dominated by opportunistic shrubs and grasses. Athens (1997, 2009) considers the Pacific rat as the underlying cause of lowland forest collapse. Only remnant populations sequestered in the least accessible habitats remain of the unique Hawaiian biota.

Olson and James (1982) estimate that the extinction of more than half the endemic avifauna of the Hawaiian Islands, including two thirds of endemic flightless, ground-nesting land birds and burrowing sea-birds, occurred between the initial human settlement and arrival of Europeans. At least 71 species or subspecies died out before the nineteenth century, and 24 have gone extinct since. The remaining populations are declining or are in danger of extinction (T. K. Pratt et al., 2006). Cats, rodents, and mongoose have been the major extinction cause for ground nesting birds (G. W. Cox, 1999). Introduced avian diseases, such as *Avipoxvirus* spp. (avian pox virus) and *Plasmodium relictum* (avian malaria), have also led to the decline of the endemic Hawaiian avifauna (Warner, 1968; van Riper III et al., 1986, 2002; Samuel et al., 2015). Avian malaria is uniquely transmitted by *Culex quinquefasciatus* (southern house mosquito), introduced before 1830 (Fonseca et al., 2000; LaPointe, 2000), the larvae of which are found in high densities in low- and mid-elevation forests, degraded by the foraging behaviour of *Sus scrofa* (feral pig; Lapointe, 2008).

Interactions amongst native pollinators and plants are considered to be important for long-term sustainability of natural island ecosystems (S. K. Walsh et al., 2019). Loss of plant-pollinating birds has disrupted plant-pollinator relations and led to plant extinctions, e.g., 31 species of bird-pollinated bellflowers, Campanulaceae, have gone extinct. Introduced *Zosterops japonicus* (Japanese white-eye) outcompetes native birds for insects and nectar (G. W. Cox, 1999), providing a replacement pollinator for *Freycinetia arborea* (ie'ie vine), once pollinated by extinct or endangered native birds (P. A. Cox, 1983; P. A. Cox & Elmqvist, 2000). *Pheidole megacephala* (big-headed ant) and *Linepithema humile* (Argentine ant) threaten the once abundant native *Hylaeus* spp. (yellow-faced bees; Perkins, 1913; Lach, 2005; Magnacca & King, 2013; Sahli et al., 2016; Plentovich et al., 2021), of which half are now extinct, threatened, or extremely rare (Magnacca, 2007). These native bees exhibit high pollinator fidelity to native species, whereas *Apis mellifera* (European honeybee) also pollinates invasive alien plant species (E. E. Wilson et al., 2010; Miller et al., 2015; Aslan et al., 2016). Endemic Hawaiian honeycreepers and insects are the most important pollinators of the iconic native tree *Metrosideros polymorpha* ('ōhi'a lehua) culturally important to the native Hawaiians (Kānaka Maoli), and a keystone species of the Hawaiian rainforest (Cortina et al., 2019). 'Ohi'a lehua trees have been in rapid decline since the 1960s (Akashi & Mueller-Dombois, 1995; Gruner, 2004) from infection by introduced *Ceratocystis* fungi (Keith et al., 2015; Barnes et al., 2018; Heller et al., 2019), likely transmitted by introduced *Xyleborus* spp. (ambrosia beetles; K. Roy et al., 2020).

As many as 90 per cent of the 750 recognized species of land snails are extinct; the once speciose Amastridae, comprising more than 300 species endemic to Hawaii, are currently reduced to 10 species (Lydeard et al., 2004). Many land snails were annihilated by *Euglandina rosea* (rosy predator snail) introduced in a failed attempt to control the previously introduced *Lissachatina fulica* (giant African land snail; G. W. Cox, 1999). The native freshwater gastropods, too are threatened with extinction or are much reduced in range (Christensen et al., 2021).

**Box 4.7. Impacts of invasive alien species on nature in Antarctica, Antarctic and sub-Antarctic Islands**

Few alien species have established on the Antarctic continent and its surrounding islands south of 60°S, within the Antarctic Treaty region, on land or in the many waterbodies on the continent, which vary greatly in salinity (Frenot et al., 2005; Cavicchioli, 2015; Hughes et al., 2015; McGeoch et al., 2015; Bergstrom, 2021). Though alien crabs, mussels and tunicates have been documented from Antarctic coasts, none have established populations (López-Farrán et al., 2021). Currently, alien taxa are limited to the Antarctic Peninsula and adjacent islands, mostly to areas under strong human pressure, such as the vicinity of research stations and sites attractive to tourists (Znój et al., 2017). They include the recently documented mussel *Mytilus* cf. *platensis* (Cárdenas et al., 2020), a chironomid midge *Eretmoptera murphyi*, for which direct evidence on impact on native species is lacking (J. C. Bartlett et al., 2020), and the fly *Trichocera maculipennis* (winter crane fly), which is yet to be explicitly confirmed as established in the natural environment (Remedios-De León et al., 2021).

Impact studies were conducted solely on the invasive alien grass *Poa annua* (annual meadowgrass) in Antarctica (Hughes et al., 2015; Baird et al., 2019; **Figure 4.11**). Experimental and modelling studies suggest that the invasive grass *Poa annua* could have impacts on the only two vascular plant species indigenous to the Antarctic: the grass *Deschampsia antarctica* (Antarctic hair grass) and the forb *Colobanthus quitensis* (Antarctic pearlwort) (Molina-Montenegro et al., 2019). Observational and experimental data of co-occurrence of vascular plant species in the Antarctic Peninsula revealed that *Deschampsia antarctica* facilitates the presence of *Poa annua* and may impact its introduction and spread (Atala et al., 2019).


**Figure 4.11.** *Poa annua* (annual meadowgrass), the only invasive alien species with documented impacts on the Antarctic continent. Source: Molina-Montenegro et al. (2019), https://doi.org/10.3897/neobiota.51.37250, under license CC BY 4.0.
Da: *Deschampsia antarctica* (Antarctic hair grass)
Pa: *Poa annua* (annual meadowgrass)
Cq: *Colobanthus quitensis* (Antarctic pearlwort)

Due to their size and extreme isolation, the Southern Cold Temperate Islands (e.g., Tristan da Cunha, New Zealand Shelf Islands), and the sub-Antarctic Islands (e.g., South Georgia and the South Sandwich Islands, Crozet Islands, Heard Island), are taxonomically and functionally depauperate, and thus, vulnerable to synanthropic introductions (Dawson et al., 2022; Frenot et al., 2005; Hughes et al., 2020).

Terrestrial mammals, absent prior to their introductions, have posed, and still pose, the most severe threats to the islands' biodiversity, ecosystem structure and landscape (McGeoch et al., 2015). Introduced feral herbivores, such as *Bos taurus* (cattle), *Rangifer tarandus* (reindeer), *Ovis aries* (sheep), and *Oryctolagus cuniculus* (rabbits), have all had significant impacts on the vegetation of the islands to which they have been introduced (Vogel et al., 1984; Chapuis et al., 1994, 2004; Whinam et al., 2014). In some cases, direct impacts led to indirect ones: on Macquarie Island, eradication of cats was followed by increasing rabbit population, resulting in island-wide ecosystem effects, altered vegetation structure, impacting burrow-nesting seabirds; on Ile Verte rabbit eradication enabled the rapid expansion of the invasive alien *Taraxacum officinale* (dandelion), and impacted both native, burrowing seabird prey populations and their predator, *Stercorarius skua* (great skua) (Chapuis et al., 2004; Scott & Kirkpatrick, 2008; Bergstrom et al., 2009; Whinam et al., 2014; Brodier et al., 2011; Houghton et al., 2019). On South Georgia and the South Sandwich Islands, reindeer caused the replacement of indigenous grasses with the introduced grazing-tolerant *Poa annua*, a poor food for the indigenous *Hydromedion sparsutum* (tussac beetle), and thus indirectly contributed to its decline (Chown & Block, 1997). *Felis catus* (cat) has had major impacts on burrowing and other seabird populations on the islands to which they were introduced

(Frenot et al., 2005). Significant recovery of some populations followed their removal (Dilley et al., 2017; Brooke et al., 2018), and was tempered, in some cases, by the increase in populations and impacts impacts of *Felis catus*' invasive alien prey (e.g., *Oryctolagus cuniculus* (rabbits); Bergstrom et al., 2009). Invasive alien rodents such as *Rattus rattus* (black rat), *Rattus norvegicus* (brown rat), and *Mus musculus* (house mouse), have had significant impacts on invertebrate populations, to the point of extirpation in some cases (V. Le Roux et al., 2002; McClelland et al., 2018; J. C. Russell et al., 2020). Rats have caused the near disappearance of terrestrial birds, such as *Anthus antarcticus* (South Georgia pipit; now recovering following rat eradication), and are also thought to be responsible for declines in the abundance of burrowing seabird species (Pye & Bonner, 1980; Jouventin et al., 2003; H. P. Jones et al., 2008; Dilley et al., 2018). Mice were documented preying on naïve chicks and adults of several albatross and burrowing petrel species (M. G. W. Jones & Ryan, 2010; Dilley et al., 2016, 2018; C. W. Jones et al., 2019).

Invasive alien predatory beetles have led to substantial declines in the abundance of their preferred invertebrate prey on Kerguelen Island (Lebouvier et al., 2011; Houghton et al., 2019). Although many plant species have become invasive on the sub-Antarctic islands, impacts were only quantified for a few of them: *Agrostis stolonifera* (creeping bentgrass) reduces the abundance of indigenous plants and alters arthropod community structure on Marion Island (Gremmen et al., 1998), and the widespread *Poa annua* outcompetes indigenous plants for space and resources, especially in coastal areas disturbed by seals and penguins (Haussmann et al., 2013; L. K. Williams et al., 2018).

#### 4.3.1.2. Protected areas

Invasive alien species frequently impact protected areas around the world (Carlton et al., 2019; Foxcroft, Richardson, et al., 2013; Galil, 2017; Macdonald et al., 1988). A report of the Working Group on Nature Reserves, associated with the SCOPE programme on the "Ecology of Biological Invasions" concluded that all nature reserves, except those in Antarctica, appear to have invasive species (Usher, 1988). Invasive alien species have reduced, or have the potential to reduce, the viability of protected areas to provide refugia for native species, habitats and the ecosystem services that they sustain (Foxcroft, Richardson, et al., 2013). Impacts on nature in protected areas represent 19.3 per cent (4,673) of the total number of impacts on nature documented in published studies. Negative impacts on native species in protected areas are far more frequent (33.2 per cent) than positive impacts (6.3 per cent; **Figure 4.12**).

There is no clear difference in the proportion of negative and positive impacts and impacts on ecosystem properties inside and outside protected areas (**Figure 4.12**), although declines of native populations seem to be higher inside protected areas than outside (20.3 per cent vs. 17.1 per cent; **Figure 4.12**). Thus, protected areas are not sheltered by their protection status from impacts of invasive alien species.

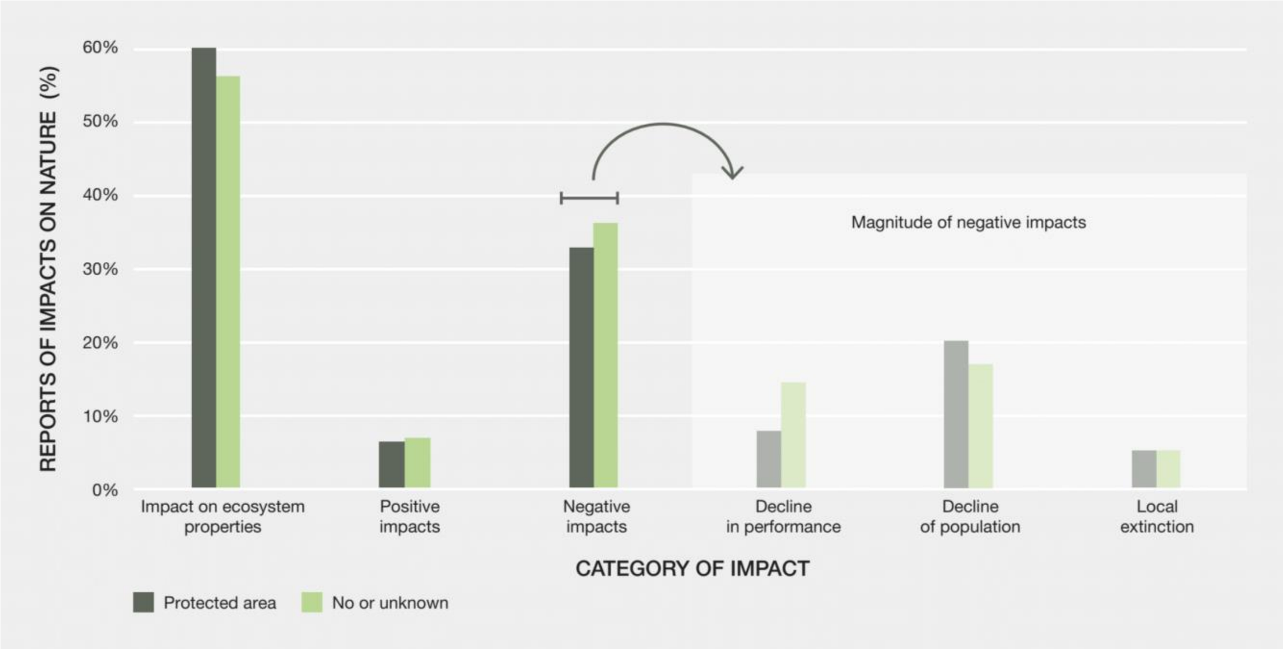


**Figure 4.12.** Percentage of reports on impacts on nature in protected areas vs. locations that were either not in a protected area or unknown. For each of the three impact categories, ecosystem properties, positive and negative impacts, the percentages sum to 1. Negative impacts are split into their impact magnitudes in the shaded box on the right-hand side. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

In protected areas, globally, 53 invasive alien species have caused 240 local extinctions of native species. *Rattus rattus* (black rat) is by far the most frequent invasive alien species causing local extinctions in protected areas, but other mammals such as *Capra hircus* (goats), *Felis catus* (cat), or *Sus scrofa* (feral pig) have also been documented multiple times. Local extinctions of a native species have not only been restricted to the terrestrial realm, but have also occurred in the marine realm caused multiple times by invasive alien species such as *Sporobolus* spp. (cordgrass), *Caulerpa taxifolia* (killer algae), *Halophila stipulacea* (halophila seagrass), *Kappaphycus alvarezii* (elkhorn sea moss), or *Mytilus galloprovincialis* (Mediterranean mussel), and in inland waters caused by *Pontederia crassipes* (water hyacinth). The microbial pathogenic *Batrachochytrium dendrobatidis* (chytrid fungus) has also caused local amphibian extinctions in protected areas.

### 4.3.1.3. Mechanisms

The mechanisms through which invasive alien species can impact native species are classified according to the EICAT (IUCN, 2020; **Box 4.2**). They include competition; predation; hybridization; transmission of disease; parasitism; poisoning or toxicity; bio-fouling or other direct physical disturbance; grazing, herbivory or browsing; chemical, physical, structural impact on ecosystems; and indirect impacts through interactions with other species (**Box 4.3** for definitions). Note that standards for classification of impact mechanisms have only been defined for negative impacts at the time of developing this assessment report; thus, positive impacts are not discussed here with respect to their different mechanisms (but see Vimercati et al., 2022).

Invasive alien species affect ecosystem properties and native species through all mechanisms leading to varying degrees of magnitude of impact. The occurrence of each mechanism is not evenly distributed across taxa and realms (**Table 4.4**). While examples of most mechanisms can be found for all invasive alien species and across realms, some mechanisms are more commonly associated with some taxa and within specific realms. For example, most reports of hybridization of an alien species with a native species relate to invasive alien vertebrates and plants, while invasive alien invertebrates and microbes seem to hybridize much less frequently with native species (**Table 4.4**). Likewise, transmission of diseases seems to be less frequent in the marine realm than in terrestrial and inland waters systems, and toxicity less frequent in the inland waters (**Table 4.4**).

**Table 4.4.** Distribution of mechanisms across invasive alien species taxa and realms
Examples are not meant to be representative but highlight invasive alien species which have caused local extinctions of native populations.

Plants:  Invertebrate:  Inland waters: 
Vertebrate:  Microorganisms:  Marine: 
Terrestrial: 

| Mechanism | Main taxa | Realms | Examples of invasive alien species |
|---|---|---|---|
| Competition |  |  | *Linepithema humile* (Argentine ant), *Solenopsis invicta* (red imported fire ant), *Caulerpa cylindracea* (green algae) |
| Predation |  |  | *Felis catus* (cat), *Vulpes vulpes* (red fox), *Pterois volitans* (red lionfish), *Lates niloticus* (Nile perch) |
| Hybridization |  |  | *Anas platyrhynchos* (mallard), *Ambystoma tigrinum* (tiger salamander), *Sporobolus densiflorus* (denseflower cordgrass) |
| Transmission of disease |  |  | *Faxonius limosus* (spiny-cheek crayfish), *Canis lupus familiaris* (dogs) |
| Parasitism |  |  | *Philornis downsi* (avian vampire fly), *Batrachochytrium dendrobatidis* (chytrid fungus), *Haplosporidium nelsoni* (MSX oyster pathogen) |
| Toxicity |  |  | *Caulerpa taxifolia* (killer algae), *Rhinella marina* (cane toad) |
| Biofouling |  |  | *Kappaphycus alvarezii* (elkhorn sea moss), *Carijoa riisei* (branched pipe coral), *Dreissena polymorpha* (zebra mussel) |
| Herbivory |  |  | *Capra hircus* (goats), *Carcinus maenas* (European shore crab), *Ctenopharyngodon idella* (grass carp) |
| Ecosystem |  |  | *Pontederia crassipes* (water hyacinth), *Caulerpa cylindracea* (green algae), *Mytilus galloprovincialis* (Mediterranean mussel) |
| Indirect |  |  | *Dreissena* spp. (zebra/quagga mussel), *Pterois volitans* (red lionfish), *Bromus tectorum* (downy brome) |

Impacts on nature by invasive alien species are most often caused by changes to ecosystem properties (26.8 per cent) and competition (23.7 per cent), followed by predation (18.4 per cent) and herbivory (12.3 per cent), i.e., direct trophic interactions. Indirect mechanisms (disease transmission and interactions with other species) only account for 8.7 per cent of all records, but this might be partly due to indirect interactions being less often studied or overlooked due to their complexity. Across all types of mechanism, changes to ecosystem properties alongside impacts of lower magnitude are more often documented than high magnitude impacts (**Box 4.2** for impact magnitudes).

Local extinctions are most often caused through hybridization (19.5 per cent), followed by impacts through predation (11.8 per cent) and direct physical interactions/biofouling (7.2 per cent) (**Figure 4.13**). Invasive alien species that are most commonly responsible for extinctions through hybridization are *Anas platyrhynchos* (mallard) and *Ambystoma tigrinum* (tiger salamander), followed by *Cervus nippon* (sika) and *Oreochromis niloticus* (Nile tilapia). Invasive alien species most frequently causing extinctions through predation are the terrestrial vertebrates *Vulpes vulpes* (red fox), *Felis catus* (cat), *Rattus* spp. (rats) and *Boiga irregularis* (brown tree snake). In the marine realm, *Pterois volitans* (red lionfish) and *Paralithodes camtschaticus* (red king crab) have caused frequent local extinctions through predation on native species. Terrestrial invertebrates are documented to have less frequently caused local extinctions through predation, and the most frequently documented species involved in local extinctions are *Anoplolepis gracilipes* (yellow crazy ant), *Pheidole megacephala* (big-headed ant), and *Euglandina rosea* (rosy predator snail).

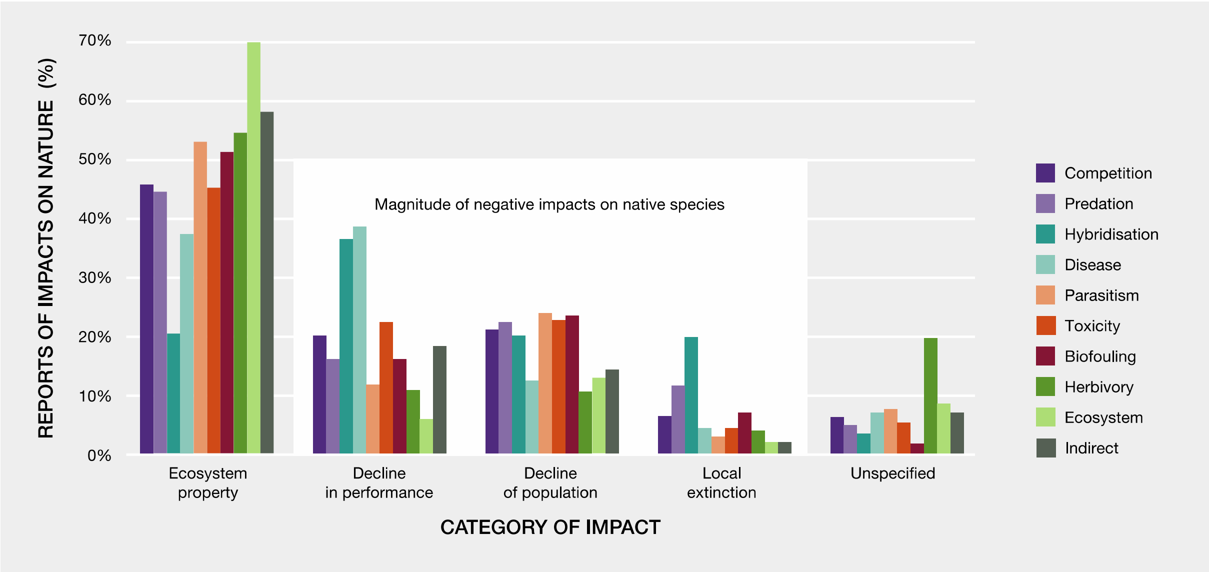


**Figure 4.13.** Percentage of reports of impacts on nature through different mechanisms. Percentage of reports (y axis) for different categories of impact on nature: ecosystem property, native species and unspecified (x axis). For each mechanism, the percentages sum to 1. Negative impacts on native species at three different magnitudes are highlighted in the shaded inset box. No mechanisms are defined for positive impacts, and these are not considered here. Mechanisms are: competition, predation, hybridization, transmission of disease, parasitism, poisoning/toxicity, bio-fouling or other direct physical disturbance, grazing/herbivory/browsing, chemical, physical, structural impact on ecosystem, and indirect impacts through interactions with other species (IUCN, 2020). A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

## 4.3.1.4. Affected native species

Most documented impacts of invasive alien species are on native plants (8,472 reports), closely followed by native invertebrates (6,253 reports) and vertebrates (5,144 reports), but the number of invasive alien species affecting native plants is much higher than for the other taxa (**Figure 4.14A**). Native microbes are rarely documented to be impacted by invasive alien species, which is most likely to be a research gap; only 1.2 per cent of documented impacts of invasive alien species relate to native microbes. There were 1,215 reports of local extinctions of native species due to 218 invasive alien species (**Table 4.5A**; **Figure 4.14A**).

The number of invasive alien species positively affecting native species is less than 10 per cent for native plants, but increases to about 15 per cent for both vertebrates and invertebrates, and is highest for native microbes (over 25 per cent; **Figure 4.14A**), which can have higher abundance in soil communities dominated by invasive alien plants (de Souza et al., 2018). The proportion of positive to negative impacts remains similar regarding the number of impacts documented except for invertebrates where the proportion of positive impacts rises to almost 25 per cent (**Figure 4.14B**). Negative impacts of invasive alien species occur most often within the same taxonomic group (**Table 4.5A**), i.e., invasive alien plants most often negatively impact native plants, and invasive alien vertebrates most often impact native vertebrates. However, this pattern does not hold for invasive alien microbes, which predominantly negatively impact plants (plant pathogens). The overall pattern is slightly different in positive impacts (**Table 4.5B**), where invasive alien plants predominantly positively affect native invertebrates, either by providing a food source or habitat structure, while invasive alien invertebrates and vertebrates mostly positively affect native species in their own taxonomic group.

Documented local extinctions caused by invasive alien species mostly affect populations of native vertebrates, followed by native invertebrates and plants (**Figure 4.14B**). Invasive alien species can also cause evolutionary responses in native species (**Box 4.8**).

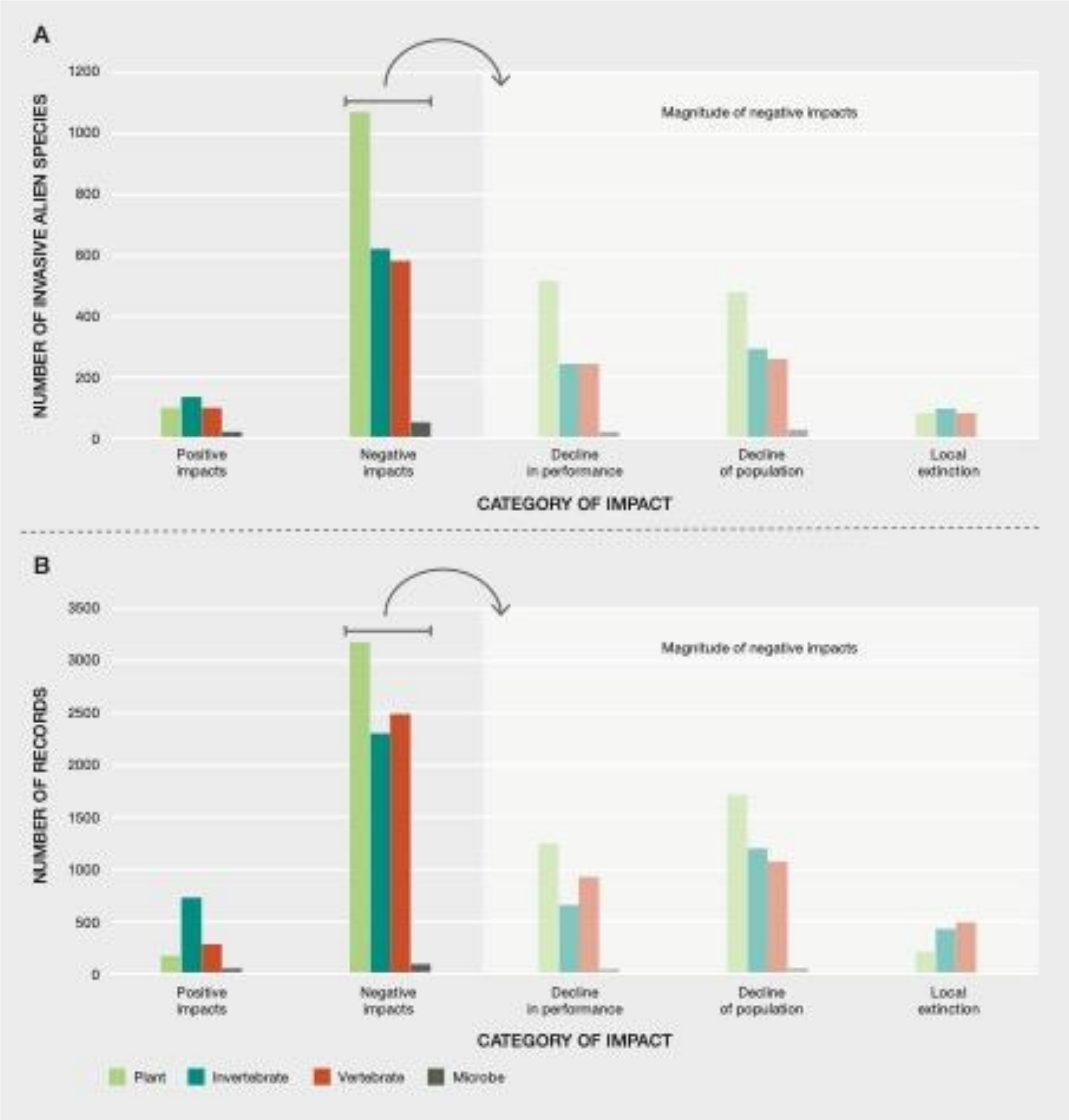


**Figure 4.14.** Number of invasive alien species A) and number of impact records B) affecting native taxa by direction and magnitude. Number of records (y axis) for different categories of impacts (x axis). Negative and positive impacts relate to the consequences for native species, while ecosystem impacts are not assigned a direction. Negative impacts in A) are subdivided for each invasive alien species into the maximum documented negative impact on a native species globally (shaded boxes on the right-hand side). Note that the same invasive alien species could have a maximum negative impact on native species from different taxa, impacts on ecosystem properties and positive impacts on native species. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

**Table 4.5.** Records of negative and positive impacts of invasive alien species on native taxa

Number of negative A) and positive B) impacts on native taxa caused by invasive alien species, documented by the chapter impact database. Impacts within the same taxonomic groups in alien and native taxa are italicized. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

**A) Negative impacts of invasive alien species on native taxa**

| Native taxa | Invasive alien species | | | |
|---|---|---|---|---|
| | *Plants* | *Invertebrates* | *Vertebrates* | *Microorganisms* |
| *Plants* | *2,542* | 795 | 462 | 283 |
| *Invertebrates* | 701 | *1,437* | 399 | 38 |
| *Vertebrates* | 336 | 418 | *2,027* | 52 |
| *Microorganisms* | 84 | 12 | 5 | *1* |

**B) Positive impacts of invasive alien species on native taxa**

| Native taxa | Invasive alien species | | | |
|---|---|---|---|---|
| | *Plants* | *Invertebrates* | *Vertebrates* | *Microorganisms* |
| *Plants* | *276* | 29 | 20 | 1 |
| *Invertebrates* | 404 | *452* | 15 | 1 |
| *Vertebrates* | 99 | 129 | *59* | -- |
| *Microorganisms* | 49 | 8 | 2 | *--* |

**Box 4.8. Invasive alien species as drivers of rapid evolutionary change in native species**

Invasive alien species often dramatically alter habitat conditions for native species. As dominant community members, they may also act as novel resources (e.g., prey) for, or threats (e.g., predators) to, native species. These changes may lead to rapid evolutionary responses in native species (Carroll, 2007; G. W. Cox, 2004; J. J. Le Roux, 2021). Generally, changes caused by invasive alien species to host plants or food resources, the bio-physical environment, mortality and reproductive rates in native species, and competitive interactions, facilitate rapid adaptive evolution in native species (J. J. Le Roux, 2021). Non-adaptive shifts in the trait values of native species may also occur in response to invasive alien species, e.g., when they hybridize with invasive alien species (Todesco et al., 2016). Alien species also often undergo rapid evolution throughout the biological invasion process which, in turn, may exacerbate their impacts (J. J. Le Roux, 2021).

The strength of selection pressure on native species brought about by invasive alien species, or vice versa, partly depends on how often these species interact and the levels of eco-evolutionary experience they share with one another (Saul et al., 2013; Saul & Jeschke, 2015). Eco-evolutionary experience describes the historical exposure of species to biotic interactions, highlighting the role of preadapted traits in driving the biological invasion success of alien species (Saul et al., 2013; Heger et al., 2019). Therefore, the eco-evolutionary experience of alien species will determine how quickly their populations become widespread, as well as the form and strength of their interactions with native species (Carroll, 2007). Selection pressures on both alien and native species are expected to be strong when native species share moderate to high levels of eco-evolutionary experience with invasive alien species, e.g., when native invertebrates colonize invasive alien plants that are closely related to their native host plants (Carroll et al., 2005). Native species lacking eco-evolutionary experience with experienced invasive alien species are also likely to experience strong selection, whereas alien species that share little eco-evolutionary experience with conditions in the new environment may fail to establish (J. J. Le Roux, 2021).

**Direct impacts**

Direct interactions between native and invasive alien species may cause rapid evolution in the native species for them to avoid, exploit, or co-exist with invasive alien species (J. J. Le Roux, 2021). Soapberry bugs in the subfamily Serinethinae provide classic examples of such impacts. As their name suggests, these bugs are herbivores of plants in the family Sapindaceae (Carroll & Loye, 2012). Given this eco-evolutionary experience, soapberry bugs have colonized various invasive Sapindaceae species in many parts of the world, often resulting in rapid evolutionary responses in these insects. For example, invasive balloon vines (genus *Cardiospermum*) have been repeatedly colonized by native *Leptocoris* soapberry bugs in Australia (Andres et al., 2013; Carroll et al., 2005) and South Africa (Foster et al., 2019). Balloon vines carry their seeds in inflated capsules, an adaptation to insect predators with piercing mouth parts. In Australia, the native soapberry bug *Leptocoris tagalicus* rapidly evolved longer proboscides (or "beaks") to increase its feeding efficiency on invasive *Cardiospermum grandiflorum* (Carroll et al., 2005). Similarly, in South Africa host shifts by native *Leptocoris mutilatus* onto two invasive balloon vines (*Cardiospermum halicacabum* and *Cardiospermum grandiflorum*), not only led to the evolution of longer beaks, but also to the formation of genetically-distinct host races (Foster et al., 2019). In the South-western United States, *Jadera haematoloma* (red-shouldered bug) shifted from its native *Cardiospermum* balloon vine host onto the invasive *Koelreuteria elegans* (goldenrain tree; Carroll & Boyd, 1992). In this instance, the bug was confronted with flatter seedpods on its new host plant, leading to the rapid evolution of shorter beaks (Carroll & Boyd, 1992; **Figure 4.15**).

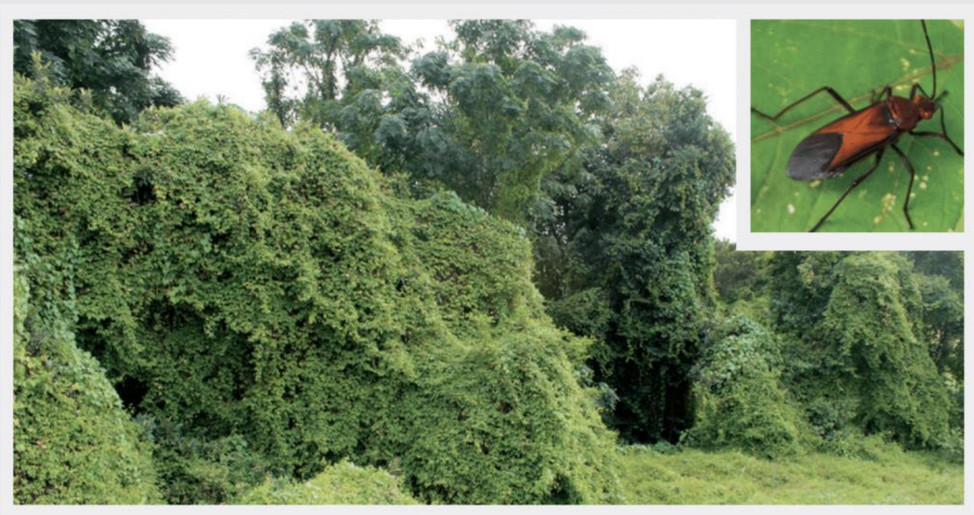

**Figure 4.15.** Native species may experience strong selection when they utilize abundant invasive alien species as novel food sources. Invasive alien balloon vines in the genus *Cardiospermum* have

been repeatedly colonized by native soapberry bugs. Shown here is the perennial balloon vine (*Cardiospermum grandiflorum*, main picture) in South Africa that has been colonized by the native bug *Leptocoris mutilatus* (inserted picture). In order to feed on balloon vine seeds more efficiently, some soapberry bug populations have rapidly evolved longer mouthparts. Photo credit: Johannes Le Roux – CC BY 4.0.

Invasive alien species may also have significant evolutionary consequences when they act as novel resources for native species. On the one hand, native predators may experience strong selection to increase their ability to capture or consume palatable invasive prey or, conversely, to avoid toxic ones. Native Australian predators of invasive *Rhinella marina* (cane toad) illustrate how quickly such evolutionary impacts can happen. *Rhinella marina* produce a potent cocktail of defensive toxins that differs in its chemical constituents from the toxins produced by native Australian anurans (Daly et al., 1987). Therefore, most Australian predators lack eco-evolutionary experience with cane toad toxins. Despite this, invasive cane toads are frequently attacked and consumed by native predators, presumably because of their superficial resemblance to Australian frogs. The amount of toxin produced by cane toads varies throughout their life cycle, with older and larger toads being more poisonous than younger and smaller ones (Hayes et al., 2009). Snakes are gape-limited, and the size of their heads thus determines the size of prey they can consume. The evolution of smaller head (or gape) size is therefore likely to occur in toad-naïve predators, because those that can swallow larger toads would be removed from the breeding population. Morphological data from four Australian snake species, spanning a period of 80 years since the arrival of cane toads, partly support this hypothesis. As predicted, Phillips and Shine (2004) found two species, *Pseudechis porphyriacus* (red-bellied black snake) and *Dendrelaphis punctulatus* (common tree snake), to have evolved smaller heads since the arrival of cane toads in Australia. By contrast, *Hemiaspis signata* (swamp snake) and *Tropidonophis mairii* (common keelback snake) did not display any evolutionary responses to invasive *Rhinella marina*. *Hemiaspis signata* already have unusually small heads, making them incapable of ingesting toads large enough to kill them (Phillips et al., 2003). While *Tropidonophis mairii* have normal-sized heads, their Asian ancestry, and thus historical exposure to poisonous toads, likely provided them with sufficient eco-evolutionary experience to tolerate their poisoning (Phillips & Shine, 2004).

Invasive alien predators may also cause strong evolutionary responses in native species. In Lombardy, Italy, invasive alien *Procambarus clarkii* (red swamp crayfish) is established in waterbodies throughout the region (Ficetola et al., 2011). Prior to its arrival, tadpoles of different populations of the native *Rana latastei* (Italian agile frog) exhibited pronounced variation in development time, depending on water temperature; this variation disappeared following the arrival of the red swamp crayfish (Melotto et al., 2020). Within 14 years of the crayfish's introduction, tadpoles of the frog developed significantly faster in invaded ponds than in uninvaded ponds, irrespective of whether these were in foothill or lowland areas. These evolutionary responses likely occurred to reduce the frog's exposure to crayfish predation by allowing earlier metamorphosis and, remarkably, occurred over just 3-6 frog generations. Invasive alien species may also act as mutualists for native species (J. J. Le Roux et al., 2020).

**Indirect impacts**
Invasive alien species may also create indirect evolutionary pressures on native species by changing abiotic and/or biotic conditions in ways that indirectly affect the fitness of native species (J. J. Le Roux, 2021). For example, along coasts of South-eastern Australia, the invasive seaweed *Caulerpa taxifolia* (killer algae), reduces water flow rates and causes anoxic sediment conditions, leading to increases in the abundance of large phytoplankton species (Gribben et al., 2009; McKinnon et al., 2009). These changes are thought to underlie the rapid evolution of longer and broader shells in the native mussel, *Anadara trapezia* (Sydney cockle), presumably for this mollusc to cope with altered sediment conditions and food resources (J. T. Wright et al., 2012). While indirect evolutionary impacts are likely common, they are hard to predict and quantify (Berthon, 2015).

Hybridization between closely related native and invasive alien species is frequently documented. Genetic introgression, i.e., when hybrid offspring backcross to one or both parental species, can dilute native gene pools and purge them of locally adapted genotypes. This may ultimately lead to the extinction of native populations (Rhymer & Simberloff, 1996; Todesco et al., 2016). A well-studied example is *Anas platyrhynchos* (mallard). This highly successful invasive alien species hybridizes with several native duck species around the world (Stephens et al., 2020). Many of these hybrids are fertile and subsequent introgression has been documented in many instances (e.g., Rhymer et al., 1994; Mank et al., 2004; Stephens et al., 2020). For example, in New Zealand, introgressive hybridization has led to the virtual elimination of *Anas superciliosa superciliosa* (New Zealand grey duck; Lavretsky, 2020).

**The ecological consequences of the evolutionary impacts of invasive alien species**
How biological invasions change and shape the evolutionary trajectories of native species is highly context-dependent and hard to predict, making inferences of long-term ecological and biodiversity impacts difficult. In the worst-case scenario, evolutionary impacts may lead to the extinction of native species. *Occidryas editha* (Edith's checkerspot butterfly) is a particularly dramatic example; it occurs in western United States and utilizes a narrow range of short-lived annual host plants. At Schneider's Meadow, Nevada, *Occidryas editha* rapidly demonstrated a rapid evolution of preference for invasive alien *Plantago lanceolata* (ribwort plantain; Singer & Parmesan, 2018). Selection for this host shift was strong, because, unlike the butterfly's native host plants, ribwort plantain provided its larvae with food year-round (Singer & Parmesan, 2018). Subsequent changes in land-use led to the recovery of grassland vegetation and the smothering of *Plantago lanceolata* plants, creating microclimatic conditions that were unsuitable for larval development. *Occidryas editha* was unable to switch back to their original native host plants at Schneider's Meadow and the local population died out (Singer & Parmesan, 2018). *Occidryas editha* is highly sedentary and therefore this local extinction likely led to the permanent loss of unique phylogenetic history.

Rapid evolution in native species may also reduce the impacts they experience from invasive alien species. For instance, in the United States, invasive *Alliaria petiolata* (garlic mustard) impacts native plants by interfering with their mycorrhizal fungal mutualists via strong allelopathy (Lankau, 2012). Invasive populations of *Alliaria petiolata* also rapidly evolved higher levels of allelopathy (Lankau et al., 2009). Lankau (2012) found native *Pilea pumila* (clearweed) to have evolved tolerance to *Alliaria petiolata* and the ability to maintain high levels of mycorrhization in invaded areas. This suggests that co-evolutionary dynamics exist between the invasive alien species and native species.

Invasive alien species may facilitate speciation. A classic example is *Sporobolus anglicus* (common cordgrass), the descendant lineage of hybrids between invasive *Sporobolus alterniflorus* (smooth cordgrass) and native *Sporobolus maritimus* (small cordgrass) (Gray et al., 1991). In another example, invasive *Lonicera* honeysuckles in North America acted as new host plants shared between two native tephritid fruit flies, *Rhagoletis mendax* (blueberry fruit fly) and *Rhagoletis zephyria* (snowberry fruit fly) (Schwarz et al., 2005). These host shifts led to the breakdown of historical ecological barriers (i.e., utilization of distinct native host plants) between the two fly species and the establishment of a genetically-distinct hybrid fly lineage that is reproductively isolated from both parent species (Schwarz et al., 2005).

The evolutionary responses of native species to invasive alien species likely ramify throughout entire communities and ecosystems, yet our understanding of such broad-scale impacts remains limited. For example, native insects may experience altered parasitoid loads when a native parasitoid evolves preference for a new and abundant invasive alien insect host. This may lead to community-wide changes in insect-host interactions.

## 4.3.2. Documented impacts of invasive alien species on nature by realm

### 4.3.2.1. Patterns of negative and positive impacts of invasive alien species on nature in the terrestrial realm

The database of impacts developed through this chapter includes more than 10,000 impacts on nature in the terrestrial realm, implicating 1,588 invasive alien species. Among these documented impacts, 76 per cent (6,638) can be considered as negative impacts, 17 per cent (1,498) as neutral and only 7 per cent (651) as positive impacts. Negative impacts in terrestrial habitats are caused by a total of 1,186 invasive alien vertebrates, invertebrates, plants or microbes.

The chapter impact database highlights that the vast majority of negative impacts caused by invasive alien species on nature are in terrestrial habitats (70 per cent). This bias towards terrestrial impacts is most likely a consequence of the rate at which humans have transported and introduced alien species through time (Seebens et al., 2017), but may also reflect a bias in terrestrial research over inland waters and marine research.

**Mechanisms and magnitude of negative impacts**

Among all the species negatively impacting terrestrial habitats, more than half (52 per cent, 619 species) cause decline in the performance of native species, almost half (45 per cent, 530 species) cause decline of local native populations, and some (9 per cent, 105 species) cause local extinctions of native species. The magnitude of negative impacts is context-dependent; some invasive alien species have impacts of different magnitudes in different invaded habitats. The highest numbers of invasive alien species causing decline in the performance of native species are found in boreal forests and woodlands, cultivated areas and tropical and subtropical dry and humid forests but the highest numbers of invasive alien species causing impact of greater magnitude, that is, population decline of native species and local extinction, are found in tropical and subtropical dry and humid forests and temperate and boreal forests and woodlands (**Table 4.6**). By contrast, tundra and high mountain habitats and deserts and xeric shrublands are the ecosystems with lowest records of negative impacts caused by invasive alien species on nature.

**Table 4.6.** Number of negative impacts of invasive alien species on nature in the terrestrial realm, by unit of analysis

Number of invasive alien species (IAS) and records of negative impacts on nature in the terrestrial realm for each unit of analysis. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

| | Maximum impact on native species | | | | | |
|---|---|---|---|---|---|---|
| | **Decline in performance** | | **Decline of population** | | **Local extinction** | |
| Unit of analysis | IAS | Records | IAS | Records | IAS | Records |
| Tropical and subtropical dry and humid forests | 144 | 404 | 160 | 586 | 46 | 282 |
| Temperate and boreal forests and woodlands | 129 | 389 | 159 | 728 | 33 | 196 |
| Mediterranean forests, woodlands and scrub | 57 | 158 | 73 | 251 | 17 | 115 |
| Tundra and high mountain habitats | 8 | 22 | 31 | 60 | 4 | 5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Tropical and subtropical savannas and grasslands | 63 | 222 | 97 | 326 | 30 | 104 |
| Temperate grasslands | 188 | 381 | 106 | 366 | 14 | 66 |
| Deserts and xeric shrublands | 20 | 50 | 31 | 64 | 9 | 85 |
| Urban/Semi-urban | 167 | 311 | 54 | 159 | 9 | 15 |
| Cultivated areas (incl. cropping, intensive livestock farming etc.) | 239 | 479 | 84 | 173 | 16 | 24 |

**Impacted units of analysis**

Temperate and boreal forests and woodlands, and tropical and subtropical dry and humid forests are the most impacted units of analysis in the terrestrial realm, with, respectively, 1,313 and 1,272 negative impacts (**Table 4.6**). Particularly, these are the habitats with the highest reports both of decline of native local populations and local extinctions caused by invasive alien species. For example, in the United States, *Lumbricus terrestris* (lob worm) can be found in temperate and boreal habitats and has caused the reduction of plant-species richness and changed plant communities in mature forests (Holdsworth et al., 2007). Some vertebrates are also invading these forests, for example *Castor canadensis* (North American beaver; IPBES, 2018a) has invaded temperate forests, but also grasslands and peatlands in southern Argentina and Chile, causing several negative ecological and economic impacts (Duboscq-Carra et al., 2021; Gaiarin & Durham, 2016; Valenzuela et al., 2013). *Castor canadensis* is considered an ecosystem engineer due to the magnitude of the changes it produces in the riparian environments - it invades by building dams which affect nutrient cycling and soil properties, chemistry, biodiversity, morphology, flow and water dynamics of rivers and streams. *Castor canadensis* builds its dams by cutting down trees, degrading riparian forests. Associated with these modifications that it generates in the environment, *Castor canadensis* facilitates the invasions of other alien species, both aquatic and terrestrial (Gaiarin & Durham, 2016; Valenzuela et al., 2013). The invasion of *Castor canadensis* has also economic impacts: the costs associated with the invasion of *Castor canadensis* in Argentina are estimated to be around 66.56 million United States dollars (US$; Duboscq-Carra et al., 2021). Tropical and subtropical humid and dry forests are amongst the most extensive ecosystems in South America and are being impacted by several invasive alien species that mostly originated from tropical areas in Asia and Africa (IPBES, 2018a). Some examples of invasive alien plant species in these habitats are *Pinus patula* (Mexican weeping pine) in Colombia (GISP, 2005); *Artocarpus heterophyllus* (jackfruit) in Brazil (Fabricante et al., 2012); *Ligustrum lucidum* (broad-leaf privet) in Argentina (Hoyos et al., 2010), and *Acacia mangium* (brown salwood) in French Guiana (Delnatte & Meyer, 2012) and Brazil (Heringer et al., 2019). According to published studies, tundra and high mountain habitats and deserts and xeric shrublands not only have the lowest number of invasive alien species causing negative impact but also have the lowest records of negative impacts among all terrestrial habitats (**Table 4.6**). For example, *Ulex europaeus* (gorse), one of the most impactful invasive alien plant species in the world (Global Invasive Species Database, 2010), is invading several high Andean regions, altering the structure of plant communities which negatively affects the composition of birds (Amaya-Villarreal & Miguel Renjifo, 2010).

**Invasive alien taxa most often documented causing negative impacts on nature in the terrestrial realm**

Invasive alien plant species are responsible for almost half (45 per cent) of all the negative documented impacts on nature in the terrestrial realm (e.g., **Box 4.9**), followed by invasive alien vertebrates (27 per cent), invertebrates (23 per cent) and microbes (5 per cent). Several invasive alien plants cause negative impacts at different levels of ecological organization, from individual species populations to native plant and animal communities to ecosystems as a whole. For example, the shrub *Lantana camara* (lantana) has adverse impacts on native understorey shrubs and herbaceous plants diversity, and affects the vegetation community composition by reducing seedling recruitment of vertebrate-dispersed seeds (Dobhal et al., 2010; Kohli et al., 2006; Prasad, 2010; Raghubanshi & Tripathi, 2009; Sundaram et al., 2012). It also increases soil nitrogen that may further favour its proliferation (Sharma, 2011). This shrub is unpalatable, and replaces native palatable herbs and reduces available forage for wild ungulates (Prasad, 2010; G. Wilson et al., 2014). Physical changes of large extensions of invaded habitats by *Lantana camara* can change habitat use of large mammals such as elephants (G. Wilson et al., 2013). In forests, increased density of this shrub is correlated with a decrease in bird diversity, with certain guilds (canopy and insectivorous birds) being more adversely affected than others (Aravind et al., 2010). *Lantana camara* also alters fire regimes by increasing the fuel load of invaded forests, leading to more intense and severe fires (Hiremath & Sundaram, 2005; Kohli et al., 2006; Sundaram et al., 2012; Tireman, 1916). Furthermore, in temperate and boreal regions of north-western Europe, *Picea sitchensis* (Sitka spruce) is assessed to be among the highest-risk alien species in Norway (Norwegian Biodiversity Information Centre, 2018; Sandvik et al., 2020) as well as in Great Britain and Ireland (Dehnen-Schmutz et al., 2022). *Picea sitchensis* severely changes ecological conditions across a significant proportion of the habitat area of red-listed habitats such as coastal *Calluna*-heathlands and coastal mires, with knock-on impacts on red-listed plants, birds and other species linked to these habitats (Hinderaker & Nielsen, 2022; Norwegian Biodiversity Information Centre, 2018; Øyen & Nygaard, 2020; Saure et al., 2013, 2014). These heathlands are now critically endangered throughout their range in western Europe, due to compound threats involving land-use change, nutrient pollution, and invasive alien species (IPBES, 2018b). Other examples of invasive alien plant species with multiple simultaneous impacts are species belonging to the Pinaceae family. Pinaceae comprises some of the most invasive tree species and at least 20 species of the genus *Pinus* are considered to be invasive in at least one region of the southern hemisphere (Richardson & Rejmanek, 2004). These invasive alien species affect the composition and structure of native plant, bird and soil arthropod communities, and displace endemic native species thereby promoting biological invasion by other alien species (León-Gamboa et al., 2010; Pauchard et al., 2015; Ziller et al., 2005). *Pinus* spp. (pine) also have positive feedback with fire due to the accumulation of dry matter, this in turn results in greater intensity and frequency of fires (Cóbar-Carranza et al., 2014; GISP, 2005; Paritsis et al., 2018; Pauchard et al., 2008, 2015; Raffaele et al., 2016; Zalba et al., 2008; **Chapter 1**, **Box 1.4**; **Chapter 3**, **sections 3.3.1.5.2** and **3.3.4.5**) and favours high *Pinus* spp. density post-fire (K. T. Taylor et al., 2017). Other examples of invasive alien plant species with several records of negative impacts on different levels of ecological organization are *Prosopis juliflora* (mesquite; **Box 4.9**), *Impatiens glandulifera* (Himalayan balsam; e.g., Kiełtyk & Delimat, 2019), *Acacia longifolia* (golden wattle; e.g., Rascher et al., 2011), *Cenchrus ciliaris* (buffel grass; e.g., Alves et al., 2018; Bonney et al., 2017), *Reynoutria japonica* (Japanese knotweed), *Robinia pseudoacacia* (black locust), and *Ailanthus altissima* (tree-of-heaven; e.g., Vilà et al., 2010). Particularly, the latter three species are the invasive alien plants with the most widespread impacts across terrestrial habitats in European countries (Vilà et al., 2010).

**Box 4.9. *Prosopis juliflora* (mesquite), an example of a high impact invasive alien plant**

*Prosopis juliflora* (mesquite; **Figure 4.16**), a tree native to the Caribbean and tropical America, is considered one of the highest impact invasive alien trees (R. T. Shackleton et al., 2014). It was deliberately introduced to 129 countries (**Figure 4.17**) to provide forage for livestock, for firewood, charcoal, as an ornamental, and to halt desertification and stabilize dunes in arid and semi-arid regions (Pasiecznik, 2001). However, this species has been documented to have negative impacts on native species, as well as on nature's contributions to people and good quality of life, throughout its introduced range (Patnaik et al., 2017). Apart from its human-assisted spread, the species also spreads rapidly, aided by wild herbivores and livestock that feed on its pods and disperse its seeds. In the Afar region, Ethiopia, *Prosopis juliflora* is estimated to have invaded an area of about 1.17 million hectares (i.e., 12 per cent of the region) over a period of 35 years (Shiferaw, Schaffner, et al., 2019)

**Figure 4.16.** *Prosopis juliflora* (mesquite) illustrations. *Prosopis juliflora* in the Cauvrey River delta in Tamil Nadu, India (top left), *Prosopis juliflora* wood being piled up for making charcoal (top right), bags of *Prosopis juliflora* charcoal being loaded up for transport to market (bottom left), and *Prosopis juliflora* flowers (bottom right). Photo credits: Bella Galil – CC BY 4.0 (top left) / Ankila J. Hiremath – CC BY 4.0 (top right, bottom left) / courtesy of Nirav Mehta – CC BY 4.0 (bottom right).

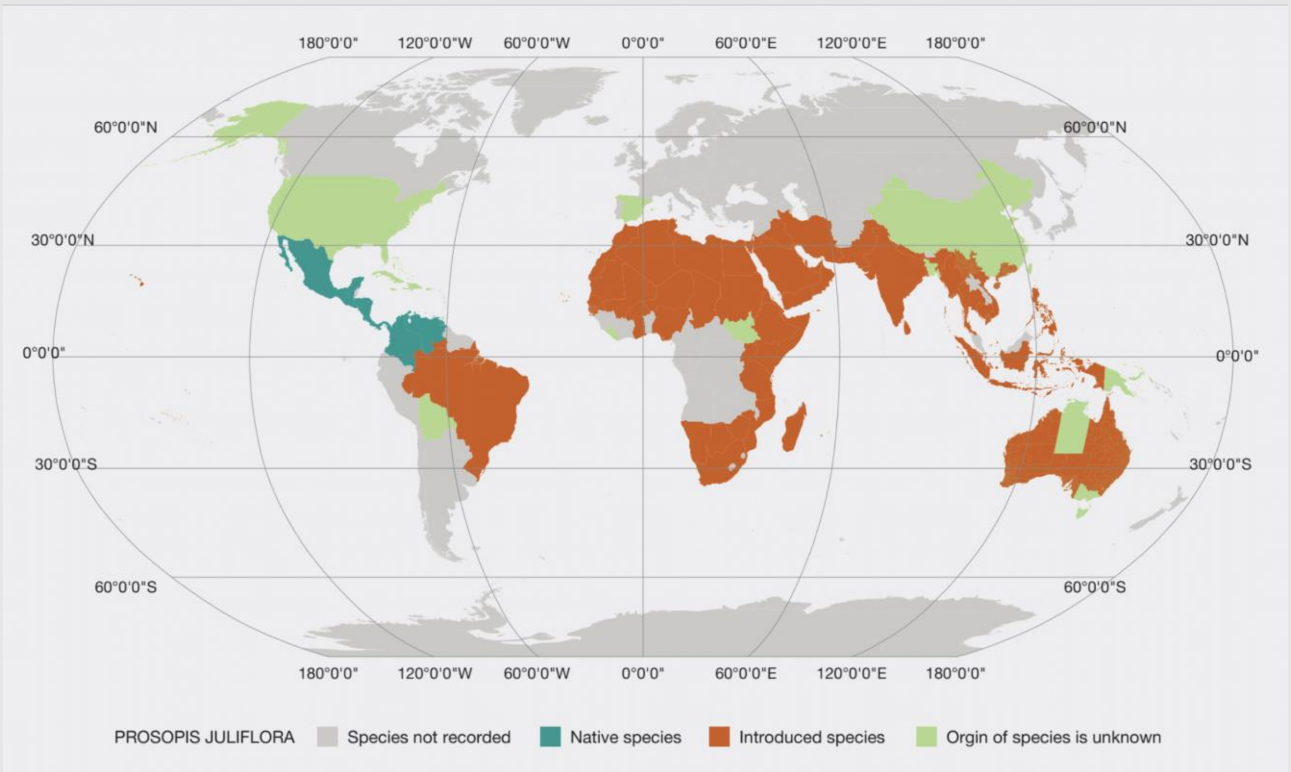

**Figure 4.17.** Global distribution of *Prosopis juliflora* (mesquite). The invasive alien plant has been documented in many countries. Data source: Pasiecznik (2022).

**Impacts on nature**

Negative impacts on nature mainly result from competition and habitat alteration. In the Brazilian Caatinga, *Prosopis juliflora* reduces the abundance of native species by more than 80 per cent, affecting seedling growth and mortality, and floristic composition, diversity, and structure of the native communities (Pegado et al., 2006). It has had direct negative impacts on wildlife by altering natural grassland and wetland habitats (Mukherjee et al., 2017; Sinha et al., 2009).

**Impacts on nature's contributions to people**

One of the main negative impacts of *Prosopis juliflora* on nature's contributions to people, throughout its introduced range, is the loss of grazing lands, e.g., in East Africa (Bekele et al., 2018; Mwangi & Swallow, 2008), and India (Duenn et al., 2017; P. N. Joshi et al., 2009). In Brazil and India, *Prosopis juliflora* has directly affected agriculture, competing with traditional short-cycle crops or encroaching tilled fields (Walter & Armstrong, 2014). It also affects agriculture indirectly due to increased crop raiding by wild herbivores as a result of reduction in wild forage availability (Sinha et al., 2009). Furthermore, it has been shown that the water use of *Prosopis juliflora* impacts on water availability (Wise et al., 2012). In the Afar Region, Ethiopia, the catchment water budget was estimated to be reduced by 3.1 to 3.3 billion $m^3$/year (Shiferaw et al., 2021). The aggregated average social annual willingness to pay (**Glossary**) to manage the biological invasion in Afar, Ethiopia, and Baringo, Kenya, is estimated at US$6.1 million and US$4.2 million, respectively (Bekele et al., 2018). *Prosopis juliflora* also provides benefits to people. For example, it is widely used by local communities in semi-arid regions of Brazil mainly for timber purposes (Guerra et al., 2014), but also potentially as a natural pesticide and in the management of diseases in crop plants (Damasceno et al., 2017). The fruits (pods) of *Prosopis juliflora* can be used to produce a number of food products; and they are extensively used for feeding livestock (Damasceno et al., 2017; Duenn et al., 2017). However, the livestock can only be fed up to a certain percentage by *Prosopis juliflora* pods, because exclusive feeding with these pods causes neurological disorders in the cattle (Patnaik et al., 2017).

**Impacts on good quality of life**

*Prosopis juliflora* has more records of negative impacts than positive impacts on good quality of life. Reports from Africa demonstrate a negative effect of *Prosopis juliflora* on the occurrence of mosquito-borne human diseases. For example, in the Baringo area, Kenya, 40 to 60 per cent of local residents documented an increase in the incidence of malaria (Mwangi & Swallow, 2008). *Prosopis juliflora* flowers provide nectar for mosquito vectors of malaria, with higher numbers of female mosquitoes documented in Malian villages surrounded by *Prosopis juliflora* (Muller et al., 2017). Further impacts include reduced access to grazing areas and water sources, resulting in conflicts among pastoralist communities due to resource scarcity; in India it has also been linked to conflicts between pastoralists and settled agriculturalists, due to livestock dispersing unwanted *Prosopis juliflora* into farmers' fields (Duenn et al., 2017). In Ethiopia, reduction in grazing lands is leading to a breakdown of traditional customary laws as people seek new grazing areas disregarding the traditional users of these areas (Shiferaw, Bewket, et al., 2019).

In heavily invaded areas, people have adapted to novel *Prosopis juliflora*-based livelihoods, especially making charcoal and harvesting the wood for sale; this livelihood diversification has enabled communities to cope better with losses of income from livestock or crops and respond to environmental shocks (Linders et al., 2020; Sato, 2013; Walter & Armstrong, 2014). The longer term consequences of these adaptation processes seem to be context dependent: while studies in

Africa found that utilization of the species was offsetting the losses, this was not expected to be sustainable in the future (Linders et al., 2020; Wise et al., 2012); whereas a study in India found that household incomes increased when the creation of small scale electricity generating facilities increased the demand for and prices of wood for energy generation following policy changes deregulating the electricity market (Sato, 2013).

Parts of the tree have traditionally been used for medicinal purposes, and people are adapting it for medicinal use in its introduced habitats (Damasceno et al., 2017; Duenn et al., 2017; Patnaik et al., 2017).

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Parts of the tree have traditionally been used for medicinal purposes, and people are adapting it for medicinal use in its introduced habitats (Damasceno et al., 2017; Duenn et al., 2017; Patnaik et al., 2017).

**Local extinctions caused by invasive alien species**

A total of 105 alien species have been documented to have caused local extinctions of terrestrial native species, with a majority documented in tropical and subtropical dry and humid forests and Mediterranean forests, woodlands and scrub. Meanwhile, fewer local extinction caused by invasive alien species have been documented in tundra and high mountain habitats and urban/semi-urban habitats (**Table 4.7**).

Invasive alien vertebrates are the main taxa responsible for local extinctions in terrestrial habitats (454 of 725 documented local extinctions have been caused by 36 invasive alien vertebrates). *Felis catus* (cat) has been documented as culpable in the greatest number of local extinctions, followed by *Vulpes vulpes* (red fox) and *Rattus rattus* (black rat) (**Figure 4.18**). These predatory invasive alien mammals have played a major role in the local extinction of native species in several terrestrial habitats (Doherty et al., 2016; Radford et al., 2018). Invasive alien invertebrates are the second taxa responsible for local extinctions of native species in terrestrial habitats (207 of 725 impacts with this magnitude have been caused by 33 invasive alien invertebrates), and most of these extinctions were registered on tropical and subtropical dry and humid forests, Mediterranean forests and temperate and boreal forests and woodlands. These invasive alien invertebrates include *Linepithema humile* (Argentine ant), *Solenopsis invict*a (red imported fire ant), *Anoplolepis gracilipes* (yellow crazy ant), and *Agrilus planipennis* (emerald ash borer). The emerald ash borer causes local extinctions of native plants through herbivory and is the focus of many studies because its larvae, feeding on ash trees, can kill the totality of ash varieties in tree stands, and, most recently, has been found to facilitate the spread of *Chionanthus* (fringetrees) in the northeast United States.

A similar number of invasive alien plants (31 species) have caused local extinctions of native species in terrestrial habitats. However, only 5 per cent (52 of 725 impacts) of all documented local extinctions have been caused by invasive alien plants. These invasive alien plant species include *Vachellia nilotica* (gum arabic tree), *Parthenium hysterophorus* (parthenium weed), and *Prosopis juliflora* (mesquite) that produced local extinctions of native species primarily due to competition (e.g., Duenn et al., 2017) and poisoning or toxicity (e.g., Batish et al., 2012).

In contrast, there are very few reports of local extinctions of native species (12 documented local extinctions) caused by only a few invasive alien microbes (5 invasive microbe species), which were documented on tropical and subtropical dry and humid forests and Mediterranean forests, woodlands and scrub. For example, the pathogenic *Batrachochytrium dendrobatidis* (chytrid fungus) has been associated with amphibian population declines, causing extinctions of frogs and salamanders in central and south America and Australia (Burrowes & De la Riva, 2017; Catenazzi et al., 2011; Lampo et al., 2008; Pounds et al., 2006; Schloegel et al., 2006).

**Figure 4.18.** Examples of terrestrial invasive alien species which can cause local or global extinctions of native species. *Felis catus* (cat, top left), *Vulpes vulpes* (red fox, top right), *Rattus* spp. (rats, bottom left), *Boiga irregularis* (brown tree snake, bottom right). Photo credits: Mark Marathon, WM Commons - CC BY-SA 4.0 (top left) / Gregory "Slobirdr" Smith, flickr - CC BY-SA 2.0 (top right) / ngamanuimages – Copyright (bottom left) / U.S. Department of Agriculture, flickr - CC BY 2.0 (bottom right).

**Table 4.7.** Main invasive alien species impacting nature in the terrestrial realm

List of alien species (top 10, by number of records of impacts) causing the maximum impacts on nature in the terrestrial realm, by the affected unit of analysis. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

Plants: Invertebrate:

Vertebrate: Microorganisms:

| Units of Analysis | Taxa | Species | # Records |
|---|---|---|---|
| Temperate and boreal forests and woodlands | | *Vulpes vulpes* (red fox) | 31 |
| | | *Linepithema humile* (Argentine ant) | 15 |
| | | *Rattus* spp. (rats) | 12 |
| | | *Lasius neglectus* (invasive garden ant) | 3 |
| | | *Lymantria dispar* (gypsy moth) | 3 |
| | | *Agrilus planipennis* (emerald ash borer) | 2 |

| | | | |
|---|---|---|---|
| | | *Castor canadensis* (North American beaver) | 2 |
| | | *Mustela erminea* (ermine) | 2 |
| | | *Sciurus carolinensis* (grey squirrel) | 2 |
| | | *Adelges piceae* (balsam woolly adelgid) | 1 |
| Cultivated areas (incl. cropping, intensive livestock farming etc.) | | *Anoplolepis gracilipes* (yellow crazy ant) | 3 |
| | | *Bombus terrestris* (bumble bee) | 3 |
| | | *Pheidole megacephala* (big-headed ant) | 2 |
| | | *Cenchrus ciliaris* (buffel grass) | 2 |
| | | *Parthenium hysterophorus* (parthenium weed) | 2 |
| | | *Paratrechina longicornis* (longhorn crazy ant) | 1 |
| | | *Plagiolepis alluaudi* (little yellow ant) | 1 |
| Deserts and xeric shrublands | | *Vulpes vulpes* (red fox) | 32 |
| | | *Bromus* spp. (bromegrasses) | 3 |
| | | *Bromus tectorum* (downy brome) | 2 |
| | | *Linepithema humile* (Argentine ant) | 1 |
| | | *Cenchrus ciliaris* (buffel grass) | 1 |
| Tropical and subtropical dry and humid forests | | *Capra hircus* (goats) | 31 |
| | | *Anoplolepis gracilipes* (yellow crazy ant) | 24 |
| | | *Boiga irregularis* (brown tree snake) | 14 |
| | | *Pheidole megacephala* (big-headed ant) | 12 |
| | | *Philornis downsi* (avian vampire fly) | 12 |
| | | *Euglandina rosea* (rosy predator snail) | 10 |
| | | *Wasmannia auropunctata* (little fire ant) | 10 |
| | | *Vulpes vulpes* (red fox) | 9 |
| | | *Sus scrofa* (feral pig) | 8 |
| | | *Batrachochytrium dendrobatidis* (chytrid fungus) | 7 |
| Temperate grasslands | | *Cenchrus ciliaris* (buffel grass) | 2 |
| | | *Vulpes vulpes* (red fox) | 2 |
| | | *Ageratina adenophora* (Croftonweed) | 1 |
| | | *Bromus tectorum* (downy brome) | 1 |
| | | *Panicum coloratum* (klein grass) | 1 |
| | | *Rosa rugosa* (rugosa rose) | 1 |
| | | *Bos taurus* (cattle) | 1 |

| | | | |
|---|---|---|---|
| | | *Crocidura russula* (greater white-toothed shrew) | 1 |
| Mediterranean forests, woodlands and scrub | | *Vulpes Vulpes* (red fox) | 31 |
| | | *Linepithema humile* (Argentine ant) | 29 |
| | | *Lasius neglectus* (invasive garden ant) | 2 |
| | | *Wasmannia auropunctata* (little fire ant) | 2 |
| | | *Eucalyptus camaldulensis* (red gum) | 2 |
| | | *Cydalima perspectalis* (box tree moth) | 1 |
| | | *Pheidole megacephala* (big-headed ant) | 1 |
| | | *Ceratocystis platani* (canker stain of plane) | 1 |
| | | *Acacia saligna* (coojong) | 1 |
| | | *Pinus radiata* (radiata pine) | 1 |
| Tropical and subtropical savannas and grasslands | | *Vulpes vulpes* (red fox) | 15 |
| | | *Vachellia nilotica* (gum arabic tree) | 7 |
| | | *Wasmannia auropunctata* (little fire ant) | 5 |
| | | *Anoplolepis gracilipes* (yellow crazy ant) | 3 |
| | | *Canis lupus familiaris* (dogs) | 3 |
| | | *Paratrechina fulva* (tawny crazy ant) | 2 |
| | | *Solenopsis geminata* (tropical fire ant) | 2 |
| | | *Capra hircus* (goats) | 2 |
| | | *Columba livia* (pigeons) | 2 |
| | | *Micropterus dolomieu* (smallmouth bass) | 2 |
| Tundra and high mountain habitats | | *Eucalyptus globulus* (Tasmanian blue gum) | 1 |
| | | *Vulpes vulpes* (red fox) | 1 |
| Urban/Semi-urban | | *Bombus terrestris* (bumble bee) | 3 |
| | | *Pheidole megacephala* (big-headed ant) | 3 |
| | | *Linepithema humile* (Argentine ant) | 2 |
| | | *Parthenium hysterophorus* (parthenium weed) | 2 |
| | | *Anoplolepis gracilipes* (yellow crazy ant) | 1 |
| | | *Myrmica rubra* (common red ant) | 1 |
| | | *Corvus splendens* (house crow) | 1 |

**Positive impacts caused by invasive alien species on nature in the terrestrial realm**

In the terrestrial realm, documented positive impacts on nature are mostly caused by invasive alien plants (**section 4.1.2**; **Box 4.3**). Highest numbers of invasive alien species causing positive impacts to native species can be found in temperate boreal forests and woodlands and temperate grasslands. Invasive alien plants causing the most documented positive impacts on native species are

*Reynoutria japonica* (Japanese knotweed), *Impatiens glandulifera* (Himalayan balsam), and *Robinia pseudoacacia* (black locust). For instance, invaded areas by *Reynoutria japonica* showed higher abundances of bumblebees, overall insect diversity and hoverfly diversity than uninvaded areas (Davis et al., 2018). Nonetheless, *Reynoutria japonica*, *Impatiens glandulifera*, and *Robinia pseudoacacia* are also invasive alien plant species with high numbers of negative impacts on nature on terrestrial habitats (**section 4.3.1**).

### 4.3.2.2. Patterns of negative and positive impacts of invasive alien species on nature in inland waters

In inland waters ecosystems the impacts of invasive alien species often act in synergy with other pressures, including unsustainable water abstraction, widespread habitat loss and degradation, overexploitation of natural resources, climate change, and other drivers of biodiversity change (Darwall et al., 2018). However, in some cases, invasive alien species are the main driver contributing to native species extinctions and population declines; for example, the precipitous decline of critically endangered amphibians has been caused by the pathogenic *Batrachochytrium dendrobatidis* (chytrid fungus) (Dueñas et al., 2021).

Concerns about inland waters ecosystems' vulnerability to invasive alien species have contributed to an increase in the number of studies on invasive alien species in inland waters (Ricciardi & Macisaac, 2011). Negative impacts of invasive alien species on nature in inland waters represent about 20 per cent of the total number of documented negative impacts caused by invasive alien species (2,113 of 10,822 impacts). A total of 230 invasive alien species have been documented to cause these impacts in inland waters.

**Mechanisms and magnitude of impacts**

Ecological impacts associated with invasive alien fishes include biotic homogenization (**Glossary**) and replacement of endemic species, spread of new diseases, changes in behaviour and diet shifts of native species (Gherardi, 2010; **Table 4.8**).

Impacts of invasive alien species on native inland waters biota and ecosystems are often synergistic and the result of multiple mechanisms such as predation and competition (Olden et al., 2021), and complex interactions. For example, invasive alien freshwater mussels require fish hosts to complete their life cycle (Modesto et al., 2018), and, in Sweden, declines in native crayfish species have been driven by the combined effects of hybridization, the transmission of crayfish plague and competitive exclusion with introduced crayfishes (Lodge et al., 2012). Other complex interactions include the facilitation by some invasive alien species of the establishment of other invasive alien species (Simberloff & Von Holle, 1999), or the contribution of some invasive alien species to multiple stressors in their introduced habitat (M. C. Jackson et al., 2016; Reynolds & Aldridge, 2021). There are synergistic interactions between invading species and cascading food-webs that may affect ecosystems within and beyond water bodies (Ricciardi & Macisaac, 2011). In North America, for example, the introduction of *Mysis relicta* (opossum shrimp) to more than a hundred lakes, to stimulate the production of *Oncorhynchus nerka* (sockeye salmon), resulted in predation-driven declines of native zooplankton to such an extent that it led to the collapse of important planktivorous fish populations and to the decline of eagle and grizzly bear populations (C. N. Spencer et al., 1991).

Decreases in native species' performance (34 per cent) or declines in local native populations (40 per cent) are the most commonly documented of all negative impacts on nature (2113 impacts) in inland waters. Local extinctions represent about 9 per cent of all documented impacts caused by invasive alien species in inland waters. For example, *Dikerogammarus villosus* (killer shrimp) caused the local extinction of the native amphipod *Gammarus duebeni* in Dutch water bodies through predation (Dick & Platvoet, 2000).

**Table 4.8.** Number of invasive alien species causing negative impacts on nature in inland waters

The number of invasive alien species (IAS) adversely impacting nature in the freshwater realm, and the number of documented negative impact by unit of analysis in relation to the maximum impact on native species: decline in performance, decline in population, local extinction or unspecified. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

| Unit of analysis | Maximum impact on native species | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Decline in performance | | Decline of population | | Local extinction | | Unspecified | |
| | IAS | Records | IAS | Records | IAS | Records | IAS | Records |
| Aquaculture areas | 14 | 17 | 21 | 58 | 1 | 1 | 14 | 15 |
| Wetlands | 44 | 91 | 52 | 156 | 10 | 22 | 37 | 87 |
| Inland surface waters and water bodies/freshwater | 132 | 613 | 125 | 636 | 54 | 168 | 94 | 249 |

**Impacted units of analysis**

In inland waters, most documented impacts (**Table 4.8**) are from inland surface waters and water bodies (78.8 per cent), and fewer from wetlands (16.8 per cent) and areas used for aquaculture (4.3 per cent). Consequently, the documented number of invasive alien species causing impacts in the freshwater realm (**Table 4.8**) is larger for inland surface waters and water bodies (209) compared to wetlands (23) and areas used for aquaculture (28). Note that the same invasive alien species might be documented causing impacts in multiple units of analysis.

**Invasive alien taxa most often documented causing negative impacts in inland waters**

Some inland waters fish act as engineering species, profoundly affecting the environment. For example, *Cyprinus carpio* (common carp) and *Ctenopharyngodon idella* (grass carp) modify aquatic vegetation directly through uprooting or herbivory and indirectly through bioturbation and excretion, ultimately shifting the trophic status of water from clear to turbid (Matsuzaki et al., 2009; Roberts et al., 1995; Vilizzi et al., 2015). *Salvelinus fontinalis* (brook trout), a widely introduced freshwater fish affecting food-webs and native diversity through various mechanisms (e.g., predation of various taxa including crustaceans, insects, amphibians and competition or hybridization with native fishes) is also causing high ecological impacts (Cucherousset et al., 2007, 2008; Orizaola & Brana, 2006).

Despite not exceeding 2 per cent of total plant diversity, aquatic plants are vital in inland waters, shaping key processes such as primary production, oxygen release, and bank stabilization (Bolpagni, 2021). In Europe, more than half of the invasive alien species considered of concern according to the European Union Regulation 1143/2014, thus deemed highly impactful, are either aquatic or wetland plants. Dense mats of floating aquatic plants (e.g., *Pontederia crassipes* (water hyacinth)) can cause the complete cover of smaller water bodies and reduce the light available to submerged plants and phytoplankton, thus depleting dissolved oxygen and altering the composition of invertebrate communities (Hill et al., 2020). Similar changes caused by thick underwater mats of *Myriophyllum spicatum* (spiked watermilfoil), leading to the decline of native macrophytes and invertebrates, have been observed in water bodies of North America (Boylen et al., 1999; Kauffman et al., 2018; S. J. Wilson & Ricciardi, 2009). Furthermore, *Myriophyllum spicatum* can affect native North American milfoils through hybridization; with the hybrid watermilfoil *Myriophyllum spicatum* x *Myriophyllum sibiricum* exhibiting an increase in reproductive potential and surface cover compared to its parental taxa (Glisson & Larkin, 2021).

The crayfish group causes many negative impacts in inland waters habitats. For instance, *Faxonius limosus* (spiny-cheek crayfish) and *Procambarus clarkii* (red swamp crayfish) interfere with water quality regulation, habitat maintenance and nutrient cycling through their burrowing activities, and decrease the abundance of macrophytes by feeding and stalk-cutting, reducing the availability of refuges for other species (Lodge et al., 2012). In Portugal, the invasive *Pacifastacus leniusculus* (American signal crayfish) threatens the survival of *Margaritifera margaritifera* (freshwater pearl mussel), a critically endangered species in Europe, through predation (R. Sousa et al., 2019). The translocation of live crayfish for aquaculture purposes has also facilitated the transmission of diseases that are potentially lethal to native crayfish (e.g., *Aphanomyces astaci* (crayfish plague); Martín-Torrijos et al., 2018) and of ectosymbiotic branchiobdellidans (e.g., *Xironogiton victoriensis* carried by its host, *Pacifastacus leniusculus*; Gelder & Williams, 2015). This creates opportunities for novel associations between, for example, alien branchiobdellidans and native crayfish, *Xironogiton victoriensis* and the endangered native *Austropotamobius pallipes* (Atlantic stream crayfish) in Spain (Martín-Torrijos et al., 2018), whose consequences are difficult to predict.

*Python bivittatus* (Burmese python) is another emerging invasive alien species, established in southern Florida. Free-ranging *Python bivittatus* have consumed a wide variety of birds, mammals, and one reptile, the *Alligator mississippiensis* (American alligator; Dove et al., 2011; Guzy et al., 2023; Rochford et al., 2010; Snow et al., 2007). Large species of mammals and birds are also vulnerable to predation by invasive pythons; *Lynx rufus* (bobcat), *Odocoileus virginianus* (white-tailed deer), and *Mycteria americana* (wood stork) have been consumed by *Python bivittatus* in the Everglades National Park (Dove et al., 2011; Guzy et al., 2023; Rochford et al., 2010; Snow et al., 2007). This large and voracious predator is directly responsible for the severe decline of several mammal populations (e.g., raccoons, opossums and rabbits; McCleery et al., 2015). By reducing populations of their native predators, invasive alien pythons might have a potential indirect positive impact on non-prey species, for example by decreasing nest predation on native turtles (Willson, 2017).

**Local extinctions caused by invasive alien species in the inland waters realm**

Several invasive alien invertebrates cause local extinctions, including *Dreissena polymorpha* (zebra mussel) and *Faxonius limosus* (spiny-cheek crayfish) (**Figure 4.19**; **Table 4.9**). The introduction of invasive alien fishes, such as *Salvelinus fontinalis* (brook trout; Cucherousset et al., 2007, 2008; Orizaola & Brana, 2006) and *Oreochromis niloticus* (Nile tilapia; Angienda et al., 2011; Wise et al., 2007), has caused local extinctions of native fishes and amphibians in all units of analysis of the inland waters realm (Cucherousset & Olden, 2011; Ellender & Weyl, 2014; **Table 4.9**). The best cited example of predation-induced extinction is the local extinction of about 200 species of endemic cichlid fish following the introduction of *Lates niloticus* (Nile perch) in Lake Victoria (Witte et al., 1992; **Box 4.10**). *Clarias gariepinus* (North African catfish) has also been documented as causing local extinctions in areas used for aquaculture purposes. In India, *Clarias gariepinus* is considered responsible for the decrease of vertebrate species richness from several ponds during the post-monsoon season (Gopi & Radhakrishnan, 2002).

Plants such as *Pontederia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce), have also caused local extinctions, mostly in wetlands (**Table 4.9**). *Pistia stratiotes* causes changes in physiochemical properties of invaded water bodies, affecting water quality and altering macrophyte communities leading, in some cases, to the local extinction of native species such as several species of the pondweed *Potamogeton* in Slovenia (Jaklič et al., 2020).

Inland waters molluscs represent one of the most diverse, but also highly threatened groups, in the inland realm (Böhm et al., 2021). The diversity and the functions they provide (e.g., biofiltration, nutrient cycling and storage, substrate and trophic resources) are essential to aquatic ecosystems and susceptible to changes (Vaughn, 2018). Invasive alien molluscs can cause the decline of phytoplankton biomass or native mussels abundance. For instance, *Dreissena polymorpha* (zebra mussel) is responsible for the 10-fold increase in the rate of local extinction of native mussels in the

Great Lakes region (Ricciardi et al., 1998). *Pomacea canaliculata* (golden apple snail) is another example of an invasive alien mollusc responsible for the increase of phytoplankton biomass through the release of nutrients when grazing (Strayer, 2010), and outcompeting native apple snails in Indonesia (Marwoto et al., 2020).

**Figure 4.19.** Examples of inland waters invasive alien species causing local/global extinctions of native species. *Pontederia crassipes* (water hyacinth, top left), *Salvelinus fontinalis* (brook trout, top right), *Dreissena polymorpha* (zebra mussel, bottom left), *Pacifastacus leniusculus* (American signal crayfish, bottom right). Photo credits: Philip, Adobe Stock – Copyright (top left) / slowmotiongli, Adobe Stock – Copyright (top right) / Thirdwavephoto, WM Commons - CC BY 4.0 (bottom left) / LFRabanedo, Shutterstock – Copyright (bottom right).

**Table 4.9.** Examples of invasive alien species causing local extinctions in inland waters, by the affected unit of analysis

The list of invasive alien species (top 10, by number of records of impacts) causing local extinctions on nature in inland waters, by the affected unit of analysis. A data management report for the database of impacts developed through this chapter is available at [https://doi.org/10.5281/zenodo.5766069](https://doi.org/10.5281/zenodo.5766069)

Plants:  Invertebrate:  Vertebrate: 

| Unit of analysis | Taxa | Invasive alien species | #records of local extinctions |
|---|---|---|---|
| Aquaculture areas |  | *Clarias gariepinus* (North African catfish) | 1 |
| Wetlands |  | *Python bivittatus* (Burmese python) | 5 |
| |  | *Sporobolus densiflorus* (denseflower cordgrass) | 3 |
| |  | *Pomacea canaliculata* (golden apple snail) | 1 |

| | | | |
|---|---|---|---|
| | | *Raffaelea lauricola* (laurel wilt) | 1 |
| | | *Sporobolus alterniflorus* (smooth cordgrass) | 1 |
| | | *Typha angustifolia* (lesser bulrush) | 1 |
| | | *Typha ×glauca* (hybrid cattail) | 1 |
| | | *Oreochromis* spp. (tilapia) | 1 |
| Inland surface waters and water bodies/freshwater | | *Pontederia crassipes* (water hyacinth) | 17 |
| | | *Salvelinus fontinalis* (brook trout) | 9 |
| | | *Dreissena polymorpha* (zebra mussel) | 8 |
| | | *Pomacea canaliculata* (golden apple snail) | 8 |
| | | *Pistia stratiotes* (water lettuce) | 8 |
| | | *Lates niloticus* (Nile perch) | 8 |
| | | *Oreochromis niloticus* (Nile tilapia) | 8 |
| | | *Faxonius limosus* (spiny-cheek crayfish) | 7 |
| | | *Procambarus clarkii* (red swamp crayfish) | 7 |
| | | *Pacifastacus leniusculus* (American signal crayfish) | 6 |

**Conflict species causing both positive and negative impacts**
Some invasive alien species can be referred to as conflict species (**Chapter 1**, **section 1.5.2**; **Chapter 5**, **section 5.6.1.2**), causing both positive and negative impacts, although this should be interpreted with caution as it is context-dependent (**Box 4.10**). Such species are challenging to manage, as they affect stakeholders in different ways (**Chapter 5**, **section 5.6.1.2**). Examples of conflict species include invasive alien macrophytes providing refuge from predators to various native species or limiting bank erosion. Likewise, invasive alien crayfish provide food or shelter for other native species, are adequate for human consumption and can be appreciated for their aesthetic properties and cultural or spiritual values (Emery-Butcher et al., 2020; Vaughn, 2018; **section 4.4.1**). Many crayfish species, like the North American *Faxonius immunis* (calico crayfish) and the parthenogenetic form of *Procambarus fallax* (slough crayfish), are kept as ornamental species in aquaria and ponds throughout Europe. This has led to a flourishing pet trade and to the inevitable escape or introduction of the crayfish in the wild with negative impacts on the native fauna (Faulkes, 2010; Holdich et al., 2009; Martin et al., 2010; Nonnis Marzano, 2009; **Chapter 3**, **section 3.2.3.2**) and on good quality of life, including cultural, social and ethical values, in many countries (Gherardi, 2011; Swahn, 2004).

**Box 4.10. Fishes as examples of invasive alien species with both positive and negative impacts**

Invasive alien species may cause both positive and negative impacts on nature, nature's contributions to people and good quality of life (Zengeya et al., 2017). Many fish have been intentionally introduced to enhance fisheries or as control agents, providing remarkable cautionary examples.

*Lates niloticus* (Nile perch), introduced in Lake Victoria, East Africa, to enhance the fishery, is a prime example (Balirwa et al., 2003; **Figure 4.20**). Lake Victoria's fish fauna was comprised of about 500 endemic haplochromine cichlid species, two tilapiine species and 46 other species belonging to 12 families (Witte et al., 2013). As increasing fishing pressure reduced the native tilapiine cichlids and other large fish species' populations, *Lates niloticus* and four tilapiine cichlids were introduced into the lake in the 1950s (Aloo et al., 2017; Gichuru et al., 2018; Luomba, 2016; Marshall, 2018). *Lates niloticus* biomass peaked at around 2.3 million tonnes in 1999, and accounted for 92 per cent of total fish biomass but fell to less than 300,000 tonnes in 2008, with average length declining from 51.7 cm to 26.6 cm, significantly below the required minimum size of 50 cm for export (Talma et al., 2014). Dramatic changes ensued: *Lates niloticus* and *Oreochromis niloticus* (Nile tilapia) increased, as well as eutrophication of the lake, and the wetlands declined. The haplochromine cichlids were the most severely hit, with most species presumed extinct. These introductions were an economic success: the annual catch is estimated at US$544 million locally, in addition to US$243 million in exports in 2003 (Balirwa, 2017), at the price of the greatest documented extinction of vertebrates (Kaufman, 1992), with an estimated loss of 200 endemic fish species (Witte et al., 1992).

**Figure 4.20.** Lates niloticus (Nile perch). Photo credit: Fotogien, Shutterstock – Copyright.

The widely introduced *Oreochromis niloticus* and four species of carps - *Ctenopharyngodon idella* (grass carp), *Hypophthalmichthys molitrix* (silver carp; **Figure 4.21**), *Hypophthalmichthys nobilis* (bighead carp), and *Cyprinus carpio* (common carp), account for more than a third of the global freshwater fish production and contribute to global food security (FAO, 2020). These fish are listed among the world's worst invasive alien species (Lowe et al., 2000). *Oreochromis niloticus* threatens native tilapia in Africa through hybridization and competition (Canonico et al., 2005). *Cyprinus carpio* suspends sediments, increasing nutrient availability and turbidity, suppressing macrophyte growth (Vilizzi et al., 2015). *Ctenopharyngodon Idella* modifies aquatic vegetation through uprooting or herbivory and has transmitted parasites which threaten wild fish (Cucherousset & Olden, 2011).

**Figure 4.21.** *Hypophthalmichthys molitrix* (silver carp). Photo credit: Ryan Hagerty/USFWS, flickr – Public domain.

Lakes and rivers worldwide were stocked with salmonids, including *Oncorhynchus mykiss* (rainbow trout), *Salmo trutta* (brown trout), and *Salvelinus fontinalis* (brook trout), for commercial and recreational exploitation. These top predators brought about profound ecological changes: predation on native fauna can reduce amphibian and reptile populations, led to changes in zooplankton and benthic macroinvertebrate species composition and size structure, alteration of nutrient cycling, competition for food and habitat, hybridization with native trout species, and disease transmission (Krueger & May, 1991; P. Jones & Closs, 2018; Miró & Ventura, 2013). Management of these and other conflict species depends on better balancing of competing goals and perspectives (Vigliano & Alonso, 2007; Ellender et al., 2014; Zengeya et al., 2017; Beever et al., 2019).

### 4.3.2.3. Patterns of negative and positive impacts of invasive alien species on nature in the marine realm

The database of impacts developed through this chapter includes about 900 articles (2,350 reported impacts) documenting quantitative observational/experimental studies of impacts of invasive alien species in the marine realm. There are 159 documented invasive alien marine species causing 1,414 negative impacts on nature, and 72 invasive alien species causing 566 positive impacts. Some of the impacts could not be given a direction (**section 4.1.2**), for example impacts on abiotic ecosystem changes.

**Impacted units of analysis**

Most impacts of invasive alien species in the marine realm have been documented in shelf ecosystems (i.e., the shallow seafloor, between the shoreline and the shelf break, generally less than 200m in water depth; **Table 4.10**). The complex interactions among invasive alien populations and the host ecosystems (**Chapter 1**, **section 1.5**; **Boxes 4.3** and **4.5**), the functions they most often affect, the relationships between changes to ecosystems, communities, and populations, and the long-term responses of ecosystems to interactions with multiple anthropogenic activities, appear to offer insurmountable challenges in the marine realm, limiting the ability to assess the overall impact of invasive alien species on marine ecosystems (Fulton et al., 2003).

**Table 4.10.** Number of impacts caused by invasive alien species in the marine realm

a. Number of invasive alien species documented as causing negative impacts on nature in the marine realm, by the affected unit of analysis, b. Number of records of negative impacts on nature in the marine realm, by the affected unit of analysis. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

**a**.

| | Decline in performance | Decline in population | Local extinction | unspecified |
|---|---|---|---|---|
| Shelf | 69 | 116 | 59 | 46 |
| Ocean | 0 | 0 | 0 | 0 |

**b**.

| | Decline in performance | Decline in population | Local extinction | unspecified |
|---|---|---|---|---|
| Shelf | 246 | 794 | 278 | 99 |
| Ocean | 0 | 0 | 0 | 0 |

**Mechanisms of impacts**

Marine invasive alien species have been shown to have differential impacts on native taxa within a biome, among different regions and ecosystems, from local extinction to food provision to rare and endangered species (**Box 4.11**).

**Box 4.11. *Magallana gigas* (Pacific oyster) in European Seas**

*Magallana gigas* (Pacific oyster; **Figure 4.22**) is the most widely cultivated and harvested shellfish species in Europe, with production totalling 142,000 tons, valued at 295 million euros (US$304 million) in 2007 (Miossec et al., 2009). It is also a highly invasive ecosystem engineer, forming reefs on hard and soft bottoms, effecting large structural changes in littoral communities. In the Wadden Sea, *Magallana gigas* brought about a shift in dominance from mussels to oysters which entailed changes of associated organisms (Kochmann et al., 2008). Yet, these complex structures provide habitat heterogeneity that can result in increased species richness, abundance, biomass, and diversity, and in the case of the Wadden Sea, replacing the ecological function of the native *Mytilus edulis* (common blue mussel) (Markert et al., 2010). A field experiment revealed that epibenthic faunal abundance and biomass was higher on (dead) oyster shells than on live animals, both favouring fish and larger invertebrate species, likely to retain the changes to benthic community structure even in the case of mass mortalities (Norling et al., 2015).

**Figure 4.22.** *Magallana gigas* (Pacific oyster) reef, Sylt I., Germany, Wadden Sea. Photo credit: G. Nehls – CC BY 4.0.

In the Bay of Mont-St.-Michel, France, extensive *Sabellaria alveolata* (honeycomb worm) reefs were damaged through trophic competition, increased silt deposition, and recreational oyster harvesting leading to trampling, breakage, and reef fragmentation (Desroy et al., 2011). The proliferating *Magallana gigas* beds impacted on birds as well: Waser et al. (2016) found that the abundances of four bird species in the Dutch Wadden Sea, *Larus canus* (common gull), *Somateria mollissima* (common eider), *Haematopus ostralegus* (Eurasian oystercatcher), and *Calidris canutus* (red knot) were reduced where mussel beds were replaced with oyster beds, which the birds were unable to feed on. Herbert et al. (2018) noted that in southeast England, areas colonized by oysters were utilized by greater numbers of oystercatchers and *Numenius* spp. (curlews), but smaller numbers of smaller shorebirds. *Larus argentatus* (European herring gull), too were disadvantaged by the replacement of mussel beds with oyster beds (Markert et al., 2013). Yet, *Larus argentatus* has soon adapted and adopted a shell-dropping behaviour utilizing pavements and parking lots (Cadée, 2001).

*Magallana gigas* have served as a major vector for introduction of algae, invertebrates and pathogens (Mineur et al., 2007; Wolff & Reise, 2002). Mineur et al. (2014) list 48 species that have likely been introduced through the Pacific Northwest to Europe route, along with the oyster trade, including notorious invasive alien species such as *Codium fragile* (dead man's fingers), *Sargassum muticum* (wire weed), *Undaria pinnatifida* (Asian kelp), the sea squirts *Botrylloides violaceus* (violet tunicate), *Didemnum vexillum* (carpet seas quirt), and *Styela clava* (Asian tunicate). The intrahemocytic parasite *Bonamia ostreae*, protozoan parasite *Marteilia refringens*, the ostreid herpesvirus (OsHV-1), and the two species of parasitic copepods *Mytilicola orientalis* (oyster redworm) and *Myicola ostreae* have all caused massive mortalities. Mineur et al. (2014) lay out a compelling case that the periodic disease outbreaks, affecting farmed *Magallana gigas* in Europe and causing major production disruptions and losses, originate in the massive imports of stock. Although providing relief to the industry in the immediate term, the translocations invariably introduce new disease agents.

**Local extinctions caused by invasive alien species in the marine realm**

Although the number of quantitative observational and experimental impact studies is limited, and most studies focus on sessile biota, shallow water and economically important species, marine invasive alien species have been documented as having significant impacts and causing local extinctions (**Table 4.11**; **Figure 4.23**). *Pterois volitans* (red lionfish) and *Caulerpa taxifolia* (killer algae) are listed among the top 10 invasive alien species that have been documented as causing most local extinctions globally (but seee Albins, 2015; Bacheler et al., 2022; Ballew et al., 2016; Ingeman, 2016; Verlaque & Fritayre, 1994; **Table 4.11**).

In the marine realm, most documented local extinctions occur on the shallow shelf, and eight of the 10 invasive alien species causing them belong to the sessile biota: in descending order, *Caulerpa taxifolia* (killer algae), *Mytilus galloprovincialis* (Mediterranean mussel), *Caulerpa cylindracea* (green algae), *Pyura praeputialis* (cunjuvoi), *Halophila stipulacea* (halophila seagrass), *Womersleyella setacea* (red alga), *Carijoa riisei* (branched pipe coral), *Kappaphycus alvarezii* (elkhorn sea moss).

The sole exception in **Table 4.11Table 4.11** is *Pterois volitans* (red lionfish), a voracious piscivore denuding the vestigial reefs in the tropical west Atlantic, documented as causing significant reduction in density, biomass and species richness of small native reef fish (Albins, 2015).

**Table 4.11.** Example of invasive alien species causing local extinctions in the marine realm

The list of invasive alien species causing local extinctions on nature in the marine realm. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

**Plants:** **Invertebrate:** **Vertebrate:**

| Taxa | Species | Records number |
|---|---|---|
| | *Pterois volitans* (red lionfish) | 39 |

| | | |
|---|---|---|
| | *Caulerpa taxifolia* (killer algae) | 21 |
| | *Mytilus galloprovincialis* (Mediterranean mussel) | 20 |
| | *Caulerpa cylindracea* (green algae) | 17 |
| | *Pyura praeputialis* (cunjuvoi) | 11 |
| | *Carcinus maenas* (European shore crab) | 9 |
| | *Halophila stipulacea* (halophila seagrass) | 8 |
| | *Womersleyella setacea* (red alga) | 8 |
| | *Carijoa riisei* (branched pipe coral) | 7 |
| | *Kappaphycus alvarezii* (elkhorn sea moss) | 2 |

Globally, in the marine realm, documented local extinctions through biofouling have been mostly caused by *Kappaphycus alvarezii* (elkhorn sea moss), *Carijoa riisei* (branched pipe coral), *Mytilopsis sallei* (Caribbean false mussel), *Polydora websteri* (mud blister worm), *Pyura praeputialis* (cunjuvoi), *Ciona intestinalis* (sea vase), *Didemnum* spp. (colonial tunicates), *Mytella strigata* (Charru mussel), and *Mytilus galloprovincialis* (Mediterranean mussel). Documented local extinctions through competition have been mostly caused by *Caulerpa cylindracea* (green algae), *Mytilus galloprovincialis* (Mediterranean mussel) and *Caulerpa taxifolia* (killer algae). Documented local extinctions through ecosystem change have been mostly caused by *Caulerpa cylindracea* (green algae), *Mytilus galloprovincialis* (Mediterranean mussel), *Pyura praeputialis* (cunjuvoi), *Eucheuma denticulatum* (eucheuma seaweed), *Womersleyella setacea* (red alga) and *Crepidula fornicata* (American slipper limpet). Documented local extinctions through herbivory have been mostly caused by *Carcinus maenas* (European shore crab), *Siganus* spp. (rabbitfish) and *Littorina littorea* (common periwinkle). Documented local extinctions through parasitism have been mostly caused by *Anguillicola crassus* (eel swimbladder nematode), *Haplosporidium nelsoni* (MSX oyster pathogen) and *Loxothylacus panopaei* (parasitic barnacle). Finally, documented local extinctions through toxicity have been mostly caused by *Caulerpa taxifolia* (killer algae) (**Figure 4.23**).

**Figure 4.23.** Examples of marine invasive alien species causing local extinctions of native species. *Pterois volitans* (red lionfish, top left), *Caulerpa* sp. (top right), *Mytilus galloprovincialis* (Mediterranean mussel, bottom left), *Carcinus maenas* (European shore crab, bottom right). Photo credits: plus69, Adobe Stock – Copyright (top left) / Coughdrop12, WM Commons - CC BY-SA 4.0 (top right) / Peter Southwood, WM Commons - CC BY-SA 4.0 (bottom left) / Nicolás Battini - CC BY 4.0 (bottom right).

**Main invasive alien species causing negative impacts in the marine realm**
*Anguillicola crassus* (eel swimbladder nematode), a blood-feeding swimbladder parasitic nematode in eels, native to eastern Asia, has been widely introduced with its native host *Anguilla japonica* (Japanese eel) for stocking and farming in Europe and North America. It is considered to have contributed to the collapse of the *Anguilla anguilla* (European eel) population. The parasite reduces endurance, while damage to the swimbladder impairs buoyancy control. High infection levels can reduce swimming performance, likely rendering the eels more susceptible to potting, predation, and hindering them from reaching their spawning grounds (Newbold et al., 2015; Palstra et al., 2007; Sjöberg et al., 2009; Sprengel & Luchtenberg, 1991). Mass mortalities of wild eels infected with *Anguillicola crassus* in Lake Balaton, Hungary, as well as laboratory results, suggested that infected eels may have been more stressed than uninfected eels by the reduced oxygen levels under high water temperatures or increased concentrations of toxicants (Bálint et al., 1997; Molnár, 1993; Molnár et al., 1991).

*Carcinus maenas* (European shore crab), native to European and North African coasts, has invaded both coasts of North America, south-eastern America, southern Australia and South Africa. It has contributed to decline in native soft-shell clams, *Mya arenaria* (sand gaper), off north-eastern America, reducing its density, and inducing deeper burrowing (de Rivera et al., 2011; Floyd &

Williams, 2004; Whitlow, 2010). Mortality of small *Crassostrea virginica* (eastern oyster) was significantly higher in the presence of *Carcinus maenas* (Poirier et al., 2017). Off central California, *Carcinus maenas* reduced the abundance of the native *Hemigrapsus oregonensis* (yellow shore crab), markedly decreased its body size and caused it to shift its habitat to the high intertidal zone (de Rivera et al., 2011; Grosholz et al., 2000). *Carcinus maenas*' predation on the Tasmanian *Katelysia scalarina* (sand cockle) reduced its population (Walton et al., 2002). *Chondrus crispus* (carrageen), a unique strain of the red alga, found solely amongst clumps of *Mytilus edulis* (common blue mussel) in a coastal lagoon in Atlantic Canada, was wiped out coinciding with *Carcinus maenas* preying on the mussel (Yorio et al., 2020). *Carcinus maenas* accounted for steep declines in in faunal organisms (Gregory & Quijón, 2011). *Zostera marina* (eelgrass) beds have been declining as a result of uprooting, grazing and cutting by *Carcinus maenas* (Garbary et al., 2004; B. R. Howard et al., 2019; Malyshev & Quijón, 2011; Matheson et al., 2016).

*Carijoa riisei* (branched pipe coral), native to the Indo-Pacific, has spread to Hawaii and the western tropical Atlantic (Concepcion et al., 2010; Grigg, 2003; Kahng & Grigg, 2005; Sánchez & Ballesteros, 2014). A large-scale survey (200 km²) of Maui's black corals revealed that at depths between 75 and 110 m up to 90 per cent of the colonies of *Antipathes dichotoma* (black coral) and *Antipathes grandis* (Pine coral) are dead, having been overgrown by *Carijoa riisei* (Grigg, 2003). It also fouls *Myriopathes* spp. (feathery black corals) and *Leptoseris* spp. (scleractinian plate corals) (Kahng, 2007; Kahng & Grigg, 2005). In the tropical eastern Pacific, *Carijoa riisei* overgrew *Pacifigorgia* seafans and *Leptogorgia* seawhips, caused community-wide octocoral mortalities, and the local extinction of some *Muricea* spp. (seafans; Sánchez & Ballesteros, 2014).

*Caulerpa cylindracea* (green algae), native to Australia, was first documented in the Mediterranean in the early 1990s, where it soon spread throughout the sea, forming dense meadows. The alga modifies habitat structure in terms of repartition of the available substrate (i.e., enhancing sediment accumulation, favours algal turfs over erect algal forms and enables them to monopolize space) (Bulleri et al., 2010). Such changes affect the associated invertebrate assemblages, algae-native species richness, cover and diversity decreased (Baldacconi & Corriero, 2009; Bulleri & Piazzi, 2015; Klein & Verlaque, 2009; Piazzi, Balata, & Cinelli, 2007; Piazzi, Balata, Foresi, et al., 2007; Piazzi et al., 2001; Vázquez-Luis et al., 2008). The effects of the colonization persist after the removal of the alga and the recovery of the assemblages appears to be quite slow: species numbers, total cover and erect perennial species cover were significantly lower than in the non-invaded plots 18 months after removal and exclusion of *Caulerpa cylindracea* (Klein & Verlaque, 2011; Piazzi & Ceccherelli, 2006).

*Caulerpa taxifolia* (killer algae) is a green alga native to tropical Australia. Since the 1980s, a cold-resistant clone has become notorious for high profile invasions in the Mediterranean, and in California, United States and Australia in the 2000s. The mat-forming invasive form of *Caulerpa taxifolia* grows rapidly, smothers seagrass beds and other benthos, replacing native macroalgal and seagrass communities. It causes a decrease in number, width, longevity of leaves, chlorosis and necrosis, and finally death of shoots of the native *Posidonia oceanica* (Neptune grass) in the Mediterranean. Furthermore, seagrass beds have never recovered their initial density, even after the decrease in *Caulerpa taxifolia* (de Villèle & Verlaque, 1995; Dumay et al., 2002; Molenaar et al., 2009). In Australia, canopy covers of *Posidonia australis* (fibreball weed) and *Zostera capricorni* (garweed) were significantly reduced (Glasby, 2013). Invertebrate assemblages (e.g., Anomura, Peracarida, Decapoda, Echinoidea, Bivalvia and Gastropoda) declined (Francour et al., 2009), but *Caulerpa taxifolia* promotes an overall increase in nematode species richness by favouring species that were absent from the native environments (Gallucci et al., 2012). The density of fish such as the commercially important *Mullus surmuletus* (red mullet) has declined, compared to native seagrass meadows (Harmelin-Vivien et al., 1996; Levi & Francour, 2004).

*Cercopagis pengoi* (fishhook waterflea), a planktonic cladoceran crustacean native to the Ponto-Aralo-Caspian Basin, has spread to the Baltic Sea. It is a voracious predator that markedly reduces the density of its prey (cladocerans, copepods) (Lehtiniemi & Gorokhova, 2008; Ojaveer et al., 2004; Põllumäe & Kotta, 2007). The population of the native cladoceran *Bosmina (Eubosmina) coregoni* (large long-nosed waterflea) has significantly declined after the invasion (Kotta et al., 2006). The reduction in zooplankton abundance may result in higher concentrations of phytoplankton (owing to reduced grazing by zooplankton), and may ultimately aggravate problems of eutrophication. Yet, *Cercopagis pengoi* has become an important food item for the three-spined and nine-spined sticklebacks, herring, sprat, and smelt (Antsulevich & Välipakka, 2000; Gorokhova et al., 2004; Ojaveer et al., 2004; Ojaveer & Lumberg, 1995).

*Crepidula fornicata* (American slipper limpet), native to the Atlantic coast of North America, has unintentionally been introduced to the Pacific coast as well as to Europe with American oysters, and has spread throughout the Atlantic coast. *Crepidula fornicata* reduces growth and increases mortality of fouled commercially important *Mytilus edulis* (common blue mussel; Thieltges, 2005a; Thieltges & Buschbaum, 2007). Yet, it reduces the infection success of cercariae and thus their parasite load (Thieltges et al., 2009), and reduces *Asterias rubens* (common starfish) predation (Thieltges, 2005b). Dense reef-like populations fundamentally alter the physical and chemical composition of the sediment when forming a novel substrate for sessile invertebrates (i.e., ascidians, tubicolous worms, bivalves) and shelters vagile invertebrates, at the loss of the infauna, deterred by the putrid biodeposits (Blanchard, 2009). Even at a moderate presence of *Crepidula fornicata*, species composition differs from the composition in its absence (de Montaudouin & Sauriau, 1999; Vallet et al., 2001). Accumulated shell debris also reduces suitable habitat for commercially valuable native flatfish (Kostecki et al., 2011; Le Pape et al., 2004).

*Didemnum vexillum* (carpet sea squirt), native to Japan, is a colonial tunicate species, widely introduced in temperate cold seas. Its massive encrusting mats, over-growing sessile biota, natural and man-made hard substrates, outcompetes other tunicates, hydroids, seaweeds, sponges, bivalves, and reduces areas suitable for settlement (Bullard et al., 2007; Lengyel, 2009; Valentine, Carman, et al., 2007; Valentine, Collie, et al., 2007). Fouled mussels and oysters have decreased growth rates and lower condition index; the swimming ability of fouled *Placopecten magellanicus* (Atlantic deep-sea scallop) is reduced, limiting their ability to escape predation and access food-rich habitats, thus affecting their survival (Dijkstra & Nolan, 2011; Kaplan et al., 2017). *Didemnum vexillum* fouling result in economic losses due to direct impact on biomass of farmed species, equipment and trade restrictions (Fletcher et al., 2013).

*Eucheuma denticulatum* (eucheuma seaweed), a red alga native to the tropical western Pacific, has been widely introduced for cultivation as one of the primary sources of carrageenan. *Eucheuma denticulatum* spread from farms into the surrounding ecosystems, overgrows and outcompetes reef-building corals, reduces seagrass beds, macroalgae, abundance and biomass of macrofauna, as well as on the benthic microbial processes and meiofauna populations. These modifications are apparent in the significant difference in the catch composition, trophic groups and diet of fish collected on coral, seagrass, sand and seaweed farms (Eggertsen et al., 2021; Eklöf et al., 2005, 2006; Johnstone & Olafsson, 1995; Kelly et al., 2020; Ólafsson et al., 1995; Tano et al., 2015; Yahya et al., 2020).

*Halophila stipulacea* (halophila seagrass), native to the Red Sea, Persian Gulf and Indian Ocean, has spread to the Mediterranean and Caribbean seas, where it forms extensive monospecific mat-forming meadows. It has displaced the native seagrasses *Syringodium filiforme* (manatee grass), *Halodule wrightii* (shoalweed), and *Halophila decipiens* (Caribbean seagrass) off Dominica, Lesser Antilles, and *Thalassia testudinum* (turtle grass) in Bonaire (Muthukrishnan et al., 2020; Smulders et al., 2017; Steiner & Willette, 2013, 2015). Continued invasion and subsequent loss of native seagrasses reduce key juvenile fish habitats in the Virgin Islands, United States (Olinger et al., 2017). Fish, as well the native sea urchin, *Tripneustes ventricosus* (white urchin), were twice as abundant in meadows of *Thalassia testudinum* as in *Halophila stipulacea* in Bonaire and the Grenadines, respectively (Becking et al., 2014; Scheibling et al., 2018). Similarly, in the Mediterranean, *Halophila stipulacea* displaced the native *Cymodocea nodosa* (slender seagrass; Sghaier et al., 2014), and the epiphytic assemblages on the latter were more abundant and more diversified (Mabrouk et al., 2021).

*Kappaphycus alvarezii* (elkhorn sea moss), a red alga native to Southeast Asia, has been widely introduced for cultivation as one of the primary sources of carrageenan. In the Gulf of Manaar, India, it has been documented as shadowing and smothering corals, seagrass, sponges and thus affecting the diverse reef-associated fauna (Chandrasekaran et al., 2008; Kamalakannan et al., 2010, 2014; Patterson et al., 2015; Patterson & Bhatt, 2012; Rameshkumar & Rajaram, 2017). Similar impacts have been noted in Venezuela and Panama (Barrios et al., 2007; Sellers et al., 2015). Studies in Hawaii suggest shading by thalli may result in coral death, but these thalli provide substrate for sessile invertebrates (ascidians, sponges) and shelter for holothurians and reef fishes (D. J. Russell, 1983).

*Loxothylacus panopaei*, a parasitic barnacle native to the Gulf of Mexico and Caribbean Sea, has spread along eastern North America, where it infects the native *Eurypanopeus depressus* (flatback mud crab). Prevalence of infection may reach upwards of 90 per cent in the invaded range (Hines et al., 1997). The parasitic barnacle induces significant behavioural changes, such as reducing mud crab activity, influencing predator-prey relationships, enhancing hiding behaviours and changes in habitat usage in infected crabs. Moreover, infection results in castration of both male and female crabs (Belgrad & Griffen, 2015; Brothers & Blakeslee, 2021; Gehman & Byers, 2017; Toscano et al., 2014).

*Mnemiopsis leidyi* (sea walnut), native to western Atlantic coastal waters, has spread to European waters (Black Sea, Caspian Sea, Mediterranean, North and Baltic Seas). The earliest records of *Mnemiopsis leidyi* in the Black Sea documented a decrease in mesozooplankton abundance and biomass, changes in diet composition of small pelagic fish, with concomitant reduction in planktivorous fishes (e.g., *Engraulis encrasicolus* (European anchovy)), their eggs and larvae (Finenko et al., 2013, 2015, 2018; Petran & Moldoveanu, 1995; Shiganova, 1997, 1998; Shiganova et al., 2003; Shiganova & Bulgakova, 2000), which were reversed, wholly or partially when *Beroe ovata* (ovate comb jelly), an invasive predator of *Mnemiopsis leidyi*, reduced its population (Finenko et al., 2018; Kamburska et al., 2003; Shiganova et al., 2003). The single study conducted in the Mediterranean Sea documented significant differences in zooplankton abundance in the zooplankton community structure (Fiori et al., 2019). Fearing an outbreak of *Mnemiopsis leidyi* similar to that which had occurred in the Black Sea motivated studies in the North and Baltic Seas (Riisgård et al., 2007). Some studies documented it severely depressed mesozooplankton stocks and influenced bacterioplankton activity and community composition in the vicinity of the jellyfish (Dinasquet et al., 2012; Riisgård et al., 2012). Yet, subsequent studies concluded *Mnemiopsis leidyi* exerted low or no direct predatory pressure on the ecologically important mesozooplankton and ichthyoplankton species and posed no threat to eggs and larvae of commercially important fish such as *Gadus morhua* (Atlantic cod), *Clupea harengus* (Atlantic herring), and *Sprattus sprattus* (European sprat) (Hamer et al., 2011; Jaspers et al., 2011; Javidpour et al., 2009; Kellnreitner et al., 2013; Schaber et al., 2011).

*Mytilus galloprovincialis* (Mediterranean mussel), native to the Mediterranean and the eastern Atlantic, has been widely introduced both intentionally for cultivation and unintentionally. It is an ecosystem engineer, and dominates wave-exposed rocky shores, increasing invertebrate density and species richness, and changing community composition (Branch et al., 2010; Griffiths et al., 1992; Hanekom & Nel, 2002; T. B. Robinson et al., 2007; T. B. Robinson & Griffiths, 2002). *Mytilus galloprovincialis* has replaced open rocky habitat with complex mussel beds, displacing the native *Choromytilus meridionalis* (black mussel) and native *Scutellastra argenvillei* (Argenville's limpet), but increasing the abundance of *Aulacomya atra* (ribbed mussel) and *Scutellastra granularis* (granular limpet) that now occur within the *Mytilus* beds (Hanekom, 2008; Hanekom & Nel, 2002; Hockey & van Erkom Schurink, 1992; Sadchatheeswaran et al., 2015; Sebastián et al., 2002; Steffani & Branch, 2005). Settling on kelp fronds, *Mytilus galloprovincialis* reduces kelp buoyancy and increases hydrodynamic drag, facilitating uprooting (Lindberg et al., 2020). Its extensive beds provide food for the rare and endangered *Haematopus moquini* (African oystercatcher; Branch & Steffani, 2004; Coleman & Hockey, 2008). In the northeast and northwest Pacific *Mytilus galloprovincialis* has extensively hybridized with *Mytilus trossulus* (northern bay mussel). On the west coast of the United States, hybrids are rare but more frequent near ports and mussel farms (Braby & Somero, 2006; Crego-Prieto et al., 2015; Heath et al., 1995; Rawson et al., 1999; Shields et al., 2010). The hybrid zone in the northwest Pacific runs from the Vladivostok area, Russia, to northern Japan (Brannock & Hilbish, 2010; Skurikhina et al., 2001; Suchanek et al., 1997). Hybridization has also been observed between native southern hemisphere *Mytilus galloprovincialis* and introduced Northeast Atlantic lineages near ports in New Zealand (Gardner et al., 2016).

*Pterois volitans* (red lionfish), a voracious predator native to the Indo Pacific, has spread to the tropical and subtropical western Atlantic and Caribbean. Its invasion has had significant negative impacts on shallow coral reef fish populations, comprising severe reductions in recruitment, total density, biomass, and species richness of prey-sized fishes, both herbivorous and piscivores (Albins, 2015; Albins & Hixon, 2008; Ingeman, 2016). A shift to an algal dominated community occurred simultaneously with the loss of herbivores, resulting in a decline in corals and sponges at mesophotic depths (Kindinger & Albins, 2017; Lesser & Slattery, 2011). By foraging away from their patch reefs residence, *Pterois volitans* eliminate a spatial refuge from predation used by juveniles of many commercially and ecologically important reef fishes (Benkwitt, 2016; DeRoy et al., 2020).

*Pyura praeputialis* (cunjuvoi), a solitary tunicate native to Australia, has spread to Chile where it monopolized the low and mid-low rocky intertidal and restricted the native mussel *Perumytilus purpuratus* (purple mussel) to the mid-upper fringe (Caro et al., 2011; Castilla et al., 2004).

*Semimytilus patagonicus* (bisexual mussel), a mytilid mussel native to the Pacific coast of South America, has spread to southwestern Africa (de Greef et al., 2013; Ma et al., 2020). On rocky, wave-exposed shores *Semimytilus patagonicus* competitively excluded co-occurring mussel species on the low-shore and native species (*Aulacomya atra* (ribbed mussel), *Choromytilus meridionalis* (black mussel)) in the mid-shore, displacing the latter to sublittoral and sand-inundated habitats (Sadchatheeswaran et al., 2015; Skein et al., 2018).

*Womersleyella setacea* is a turf-forming red alga introduced into the Mediterranean Sea. It has invaded areas where several turf species were absent or evinced lower cover values (Piazzi, Balata, & Cinelli, 2007), causing changes to biodiversity and cover of the epiphytic assemblage of *Posidonia oceanica* (Neptune grass), a species that is endemic to the Mediterranean Sea (Antolić et al., 2008). Some sponge species overgrown by the *Womersleyella setacea* were unable to reproduce, others significantly reduced their reproductive effort (de Caralt & Cebrian, 2013). Following its introduction, colonies of the Mediterranean gorgonian *Paramuricea clavata* (chameleon sea fan), an important structural species in coralligenous assemblages, demonstrated lower survivorship of juvenile colonies, higher necrosis rates and lower biomass (Cebrian et al., 2012).

## 4.3.3. Documented impacts of invasive alien species on nature by region and by taxon

The number of documented negative and positive impacts on nature by invasive alien species varies greatly across regions (**Table 4.12**).

**Negative impacts of invasive alien species across regions**

In most regions, plants generally have the greatest number of invasive alien species causing negative impacts (**Table 4.12A**), except in the Americas, where a large number of invasive alien invertebrates have caused local extinctions (**Table 4.12C**; 41 species), and in Asia-Pacific, where a large number of local extinctions have been caused by invasive alien vertebrates (**Table 4.12B**; 339 documented impacts). *Felis catus* (cat) is responsible for the greatest number of documented local extinctions across all regions (108 records), but mostly in the Asia-Pacific region (**Box 4.11**) and on the Galapagos Islands. Microbes generally have the lowest number of documented impacts across all regions, mostly causing population declines in Europe and Central Asia (**Table 4.12D**; 142 records). The microbe species with the greatest number of documented negative impacts is the oomycete plant pathogen, *Phytophthora ramorum* (38 records), which is known to cause the sudden oak death disease.

**Positive impacts of invasive alien species across regions**

Positive impacts have been documented in all regions, but the number of invasive alien species with positive impacts (361 species) is substantially lower than the number of species with negative impacts (1623 species). The number of invasive alien plants in the Americas have been documented to be the largest number of invasive alien species with positive impacts, globally (**Table 4.12A**; 109 species). Invasive alien plants in Europe and Central Asia have been documented to cause the greatest number of positive impacts, globally (**Table 4.12A**; 406 records).

The invasive alien plant with the greatest documented number of positive impacts on nature is *Robinia pseudoacacia* (black locust; 55 records), often resulting in increase in abundance and richness of native pollinators attracted to the abundant production of nectar by this alien plant. *Robina pseudoacacia* (black locust) also has 44 documented negative impacts on nature (Vítková et al., 2017).

*Dreissena polymorpha* (zebra mussel) is the invasive alien species with the greatest number of positive documented impacts on native species (143 impacts). *Dreissena polymorpha* has positive impacts on a wide range of native species, mostly invertebrates, through water filtering, thereby changing water chemistry and turbidity, which in turn favours littoral invertebrate communities, but disfavours planktonic communities (Strayer, 2009). *Dreissena polymorpha* is also in the top ten invasive alien invertebrate species causing negative impacts (85 records), and the nature of the invasion by the species (particularly in North America) and the conflicting interpretation of its impacts has been well documented (Strayer, 2009).

**Table 4.12.** Number of invasive alien species causing positive and negative impacts on nature by region

The number of plants A), vertebrates B), invertebrates C), microbes D) causing positive and positive impacts by region and by taxa. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

A) Plants: Number of invasive alien species (number of impacts)

| Region | Negative impacts caused by invasive alien plants | | | | Positive impacts |
|---|---|---|---|---|---|
| | **Ecosystem impacts** | **Impacts on individuals** | **Population declines** | **Local extinction** | |
| Africa | 131 (576) | 83 (153) | 65 (184) | 8 (31) | 10 (28) |
| Americas | 408 (2494) | 151 (393) | 196 (727) | 21 (48) | 109 (337) |
| Asia-Pacific | 246 (1034) | 182 (364) | 109 (307) | 19 (52) | 42 (103) |
| Europe and Central Asia | 129 (3767) | 47 (174) | 103 (805) | 12 (55) | 46 (406) |
| Antarctica | | 1 (1) | | | |

B) Vertebrates: Number of invasive alien species (number of impacts)

| Region | Negative impacts caused by vertebrates | | | | Positive impacts |
|---|---|---|---|---|---|
| | **Ecosystem impacts** | **Impacts on individuals** | **Population declines** | **Local extinction** | |
| Africa | 37 (132) | 37 (93) | 31 (107) | 13 (45) | 2 (3) |
| Americas | 49 (576) | 101 (313) | 60 (360) | 30 (196) | 17 (45) |
| Asia-Pacific | 139 (1589) | 117 (505) | 92 (620) | 37 (339) | 21 (58) |
| Europe and Central Asia | 31 (138) | 76 (222) | 39 (92) | 22 (39) | 5 (11) |
| Antarctica | 1 (4) | | 1 (2) | | 1 (1) |

C) Invertebrates: Number of invasive alien species (number of impacts)

| Region | Negative impacts caused by invertebrates | | | | Positive impacts |
|---|---|---|---|---|---|
| | **Ecosystem impacts** | **Impacts on individuals** | **Population declines** | **Local extinction** | |
| Africa | 67 (397) | 30 (58) | 8 (45) | 6 (39) | 4 (37) |
| Americas | 241 (1046) | 81 (451) | 86 (407) | 41 (154) | 37 (400) |
| Asia-Pacific | 92 (522) | 75 (212) | 67 (176) | 26 (117) | 25 (57) |
| Europe and Central Asia | 237 (1196) | 43 (150) | 45 (226) | 25 (83) | 34 (169) |

D) Microbes: Number of invasive alien species (number of impacts)

| Region | Negative impacts by microbes | | | | Positive impacts |
|---|---|---|---|---|---|
| | **Ecosystem impacts** | **Impacts on individuals** | **Population declines** | **Local extinction** | |
| Africa | 23 (45) | 1 (1) | | | |
| Americas | 26 (125) | 4 (9) | 17 (58) | 4 (10) | 2 (3) |

| | | | | | |
|---|---|---|---|---|---|
| Asia-Pacific | 11 (18) | 11 (15) | 9 (17) | 3 (4) | |
| Europe and Central Asia | 16 (189) | 7 (44) | 12 (142) | 1 (1) | 1 (1) |

**Native species impacted by invasive alien species across regions**

Native plant species are generally the most often negatively affected taxa across all regions. However the large number of local extinctions of native vertebrates in Asia-Pacific (**Table 4.13B**; 284 records) and of native invertebrate species in the Americas and Asia-Pacific regions (**Table 4.13C**) constitute exceptions to this general pattern. *Linepithema humile* (Argentine ant) has been documented to cause the greatest number of local extinctions of native invertebrate species across all regions, mostly by outcompeting native ants, but also through predation on native invertebrates. Native microbes generally have the lowest number of documented impacts by invasive alien species across all regions, with the highest number of negative impacts being native microbe population declines in Europe and Central Asia (**Table 4.13D**; 24 records). The perennial woody shrub *Rosa rugosa* (rugosa rose) has caused the greatest number of documented population declines in native microbes (5 records), through changes in soil chemistry, particularly in coastal dune habitats (Stefanowicz et al., 2019).

**Table 4.13.** Number of invasive alien species causing impacts on native taxa by region

The number of invasive alien species impacting A) native plants, B) vertebrates, C) invertebrates and D) microbes and the number of documented impacts (in brackets) in each region. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

A) Number of invasive alien species impacting native plants (number of impacts)

| Region | Ecosystem impacts | Impacts on individuals | Population declines | Local extinction | Positive impacts |
|---|---|---|---|---|---|
| Africa | 203 (610) | 103 (159) | 68 (99) | 8 (8) | 1 (2) |
| Americas | 496 (1554) | 187 (397) | 240 (675) | 28 (81) | 76 (130) |
| Asia-Pacific | 287 (884) | 232 (478) | 134 (320) | 27 (64) | 16 (20) |
| Europe and Central Asia | 269 (2030) | 67 (216) | 114 (620) | 22 (58) | 11 (30) |

B) Number of invasive alien species impacting native vertebrates (number of impacts)

| Region | Ecosystem impacts | Impacts on individuals | Population declines | Local extinction | Positive impacts |
|---|---|---|---|---|---|
| Africa | 87 (209) | 37 (67) | 68 (112) | 10 (38) | 6 (19) |
| Americas | 124 (679) | 98 (310) | 90 (383) | 32 (142) | 36 (93) |
| Asia-Pacific | 169 (1189) | 111 (356) | 105 (469) | 35 (284) | 40 (89) |
| Europe and Central Asia | 53 (293) | 70 (188) | 51 (114) | 17 (28) | 19 (71) |
| Antarctica | 1(4) | | 1 (2) | | 1 (1) |

C) Number of invasive alien species impacting native invertebrates (number of impacts)

| Region | Ecosystem impacts | Impacts on individuals | Population declines | Local extinction | Positive impacts |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Africa | 55 (171) | 24 (29) | 38 (87) | 10 (37) | 12 (41) |
| Americas | 225 (996) | 109 (329) | 110 (379) | 44 (162) | 58 (439) |
| Asia-Pacific | 123 (532) | 73 (161) | 89 (257) | 36 (154) | 36 (81) |
| Europe and Central Asia | 159 (1501) | 64 (139) | 90 (477) | 24 (86) | 34 (180) |
| Antarctica | | 1 (1) | | | |

| D) Number of invasive alien species impacting native microbes (number of impacts) | | | | | |
|---|---|---|---|---|---|
| Region | Ecosystem impacts | Impacts on individuals | Population declines | Local extinction | Positive impacts |
| Africa | 4 (4) | 1 (1) | | | |
| Americas | 37 (83) | 12 (21) | 12 (16) | 2 (4) | 8 (14) |
| Asia-Pacific | 15 (27) | 3 (4) | 11 (13) | 1 (1) | 6 (9) |
| Europe and Central Asia | 25 (140) | | 9 (24) | | 7 (10) |

**Box 4.12. Impacts of fox and cat predation in Australia**

Multiple studies have established that *Felis catus* (cat) and *Vulpes vulpes* (red fox) have had particularly significant impacts on, and continue to threaten, many native Australian vertebrate species (Doherty et al., 2016; Hunter et al., 2018; Radford et al., 2018; Saunders et al., 2010; Woinarski et al., 2015). *Vulpes vulpes* has been shown to suppress populations of *Petrogale lateralis* (black-footed rock-wallaby; Kinnear et al., 1988, 1998; **Figure 4.24**), *Dasyurus geoffroii* (western quoll; Morris et al., 2003), ground-dwelling and arboreal mammals (Hunter et al., 2018), medium-sized marsupials (Dexter & Murray, 2009), and even large species such as *Macropus giganteus* (eastern grey kangaroo; Banks et al., 2000). When not controlled, *Vulpes vulpes* also reduce abundance of *Varanus gouldii* (sand goanna), diurnal scincid lizards (Olsson et al., 2005), and *Varanus varius* (lace monitor; Hu et al., 2019), and can destroy turtle nests, severely impacting their populations (R.-J. Spencer et al., 2006; Limpus & Reimer, 1994). *Vulpes vulpes* have also been implicated in colonial seabird (Norman, 1971), *Leipoa ocellata* (malleefowl; Wheeler & Priddel, 2009; S. L. Williams, 1995), and ground-foraging passerine declines (Ford et al., 2001).

*Felis catus* is currently considered the single most significant threat to Australian mammals (Frank et al., 2014; Woinarski et al., 2015). Indeed, *Felis catus* has been implicated in approximately two thirds of Australian native mammal extinctions, and another 54 native mammal taxa have suffered severe range contractions and are seriously threatened by cat predation. *Felis catus* caused local extirpation of a native rodent, *Rattus villosissimus* (long-haired rat) in a Northern Territory tropical savanna (Frank et al., 2014), and has been identified as a factor contributing to northern Australian mammal declines (Woinarski et al., 2011; D. O. Fisher et al., 2014). Davies *et al.* (2017) demonstrated that *Felis catus* predation on threatened *Conilurus penicillatus* (brush-tailed rabbit-rat) is driving the remnant population to extinction on Melville Island, suggesting that predation has likely been a significant driver of *Conilurus penicillatus* decline throughout northern Australia (**Figure 4.24)**. Additionally, predation of juvenile *Dasyurus viverrinus* (eastern quoll) by *Felis catus* is likely inhibiting recovery of low-density quoll populations across Tasmania (Fancourt et al., 2015).

**Figure 4.24.** Examples of native species with serious population declines due to invasive alien species. *Petrogale lateralis* (black-footed rock-wallaby, left), *Leipoa ocellata* (malleefowl, middle), *Conilurus penicillatus* (brush-tailed rabbit rat, right). Photo credit: Kym Nicolson, WM Commons - CC BY 4.0 (left) / butupa, WM Commons - CC BY 2.0 (middle) / Hugh Davies – CC BY 4.0 (right).

There is clear evidence to implicate predation by *Felis catus* in the loss of wildlife populations at a local and regional scale, but the contribution of *Felis catus* predation to Australian extinctions or extirpations is hard to disentangle from confounding other threats such as habitat clearance, changing fire regimes, and other feral vertebrates. On offshore islands, where confounding factors are less severe, *Felis catus* have been shown to decimate native fauna (D. C. Duffy & Capece, 2012). Predation has caused the extinction of *Cyanoramphus novaezelandiae erythroti* (Macquarie Island Parakeet; R. H. Taylor, 1979), *Traversia lyalli* (Stephens Island wren; Galbreath, 2004), and the extirpation from Marion Island of *Pelecanoides urinatrix* (common diving petrel; Bloomer & Bester, 1991; Cooper et al., 1995).

In addition to direct extinction of species, *Felis catus* predation can have significant knock-on effects at the ecosystem level, through alteration of ecosystem functioning. The local extinction of fossorial mammals (i.e., those that dig burrows underground), in Australian arid and semi-arid regions (Tuft et al., 2021; Doherty et al., 2017) has caused a loss of key soil-engineering processes, negatively impacting associated plant communities (James & Eldridge, 2007; Eldridge & James, 2009; James et al., 2011).

# 4.4. Impacts of biological invasions on nature's contributions to people

## 4.4.1. General patterns

Globally, the impact database collected through this chapter contains 6,211 impacts of invasive alien species on nature's contributions to people. The economic costs of invasive alien species are presented in **Box 4.13**. Impacts on nature's contributions to people can be negative or positive (**section 4.1.2**); they are considered negative when humans are harmed and positive when humans benefit from changes in nature's contributions to people by invasive alien species. In total, there is evidence of 4,905 negative impacts (78.9 per cent of all impacts on nature's contributions to people) caused by 1,337 invasive alien species on all nature's contributions to people categories, indicating the multiplicity of impacts that invasive alien species can have beyond nature (Vilà et al., 2010). There are also 421 invasive alien species that have caused 1306 positive impacts (20.8% of all impacts on nature's contributions to people; **Figure 4.28**).

**Box 4.13. The economic costs of biological invasions**

There are many case studies of economic costs of biological invasions worldwide (Dana et al., 2014; Diagne, Leroy, et al., 2020). As a result, these costs display a very high degree of heterogeneity (e.g., nature, origin, type, implementation, estimation approach, spatial and temporal scales) and lack standardized methods that would have allowed relevant compilations and comparisons, which in turn may provide key insights for management actions (Diagne, Catford, et al., 2020). In addition, as costs are most often provided at the local scale, global estimations are very scarce while biological invasions still remain an increasingly planet-wide issue (Diagne, Catford, et al., 2020; Diagne, Leroy, et al., 2021; Latombe et al., 2017; Pagad et al., 2018). Consequently, the only global figures available up to recently were based on a handful of studies that used crude extrapolations from individual estimations (Kettunen et al., 2009; Pimentel et al., 2001), much criticized by ecologists and economists alike (e.g., Bradshaw et al., 2016; Hoffmann & Broadhurst, 2016; T. P. Holmes et al., 2009). Yet, these pioneer studies had the merit to suggest very high economic costs, and then trigger more robust assessments on many taxa or regions, as well as some more robust, global estimates, for example on a given economy sector (Paini et al., 2016). Recently, the InvaCost project[4] has compiled a wealth of individual cost estimates in a public and updatable database and has devised a standardized method of calculating economic costs of biological invasions (Diagne, Leroy, et al., 2020). This allows many comprehensive analyses of this particular dimension of impacts of biological invasions (Diagne, Catford, et al., 2020).

The main results of these analyses (see Diagne, Leroy, et al., 2021 for the very first analysis) are that (i) the global economic costs of biological invasions over the last 50 years (1970-2019) are massive, at least US$1,738 billion[5] if only the most robust data are taken into account (**Figure 4.26**); (ii) these costs are increasing exponentially with a four-fold increase each decade[6] (**Figure 4.25**); (iii) being based on already published and collated studies, the costs are massively underestimated (for example, currently occurring costs are not yet documented for most economically harmful invasive alien species and invaded countries) and (iv) management expenditures represent a very small fraction of the total costs, with damage cost recently shown to constitute 92 per cent of the total cost estimated (Cuthbert et al., 2022). In 2017 alone, aggregate global invasive alien species invasion costs were estimated to reach until US$162.7 billion,

[4] www.invacost.fr
[5] Equivalent 2017 US$
[6] Based on new analyses using the latest version of the InvaCost database (version 4.0) available at the time of writing this report (Leroy et al., 2022, 2021)

exceeding the 2017 gross domestic product (GDP) of 52 of the 54 countries on the African continent, and more than twenty times higher than the combined total funds available in 2017 for the World Health Organization (WHO) and the United Nations (Diagne, Leroy, et al., 2021). Applying a similar method (Leroy et al., 2022) to the most up-to-date version of InvaCost (at the time of writing this report) has led to an upper prediction of US$423.3 billion for the year 2019.[7]

There are now a number of published analyses from this database. For now, they are mostly descriptive and synthesize economic costs of invasions in different regions of the world or from different invasive alien taxonomic groups. Studies with a geographical focus have shown that reported costs are more important in some regions, such as North America (Crystal-Ornelas et al., 2021) and Asia (Liu et al., 2021), and less so in regions such as Europe (Haubrock, Turbelin, et al., 2021), Africa (Diagne, Turbelin, et al., 2021) and South and Central America (Heringer et al., 2021), most probably due to knowledge gaps. Studies have also been conducted at the country level: in Argentina (Duboscq-Carra et al., 2021), Australia (Bradshaw et al., 2021), Brazil (Adelino et al., 2021), Canada (Vyn, 2022), Ecuador (Ballesteros-Mejia et al., 2021), France (Renault et al., 2021), Germany (Haubrock, Cuthbert, Sundermann, et al., 2021), India (Bang et al., 2022), Japan (Watari et al., 2021), Mexico (Rico-Sánchez et al., 2021), New Zealand (Bodey et al., 2022), Russia (Kirichenko et al., 2021), Singapore (Haubrock, Cuthbert, Yeo, et al., 2021), Spain (Angulo, Ballesteros-Mejia, et al., 2021) the United Kingdom (Cuthbert, Bartlett, et al., 2021) and in the United States (Fantle-Lepczyk et al., 2021). Interestingly, the large number of countries already surveyed show both commonalities (such as high, underestimated and increasing costs) and specificities (such as the costliest species, the most impacted sectors or the proportion of management expenditures versus damage costs).

Studies focusing on the economic impact of particular taxonomic groups are fewer for now, mostly due to a lack of reported costs in the literature, but the following have sufficiently high cost data to have warranted dedicated studies: fishes (Haubrock et al., 2022), bivalves (Haubrock, Cuthberg, et al., 2021), crayfishes and crabs (Kouba et al., 2021), terrestrial invertebrates (Renault et al., 2022), aquatic species (Cuthbert, Pattison, et al., 2021), or ants (Angulo et al., 2022). As cost data accumulate, other syntheses are being prepared.

Because InvaCost is a living database, it is regularly being updated, and published studies based on it may refer to earlier versions, with actual costs having increased since then. For this reason, a "living figure", directly linked to the latest version of the database and automatically updated, is available online (Leroy et al., 2021). In addition, different studies have used different strategies regarding the filtering steps of their dataset processing. As a consequence, cost estimates highlighted in those studies may not necessarily be comparable. For example, most (but not all) studies focused on "observed" costs and those classified as "highly reliable" from a methodological point of view (**Figure 4.26**). As a result, all the cost estimates provided should be considered as relative orders of magnitude, which remains a good indication of both the reported costs and the knowledge gaps.

From the living cost figure, in which all costs filters are identical, and which therefore allows meaningful comparisons, one can assess the costliest invasive alien species and the most impacted invaded regions, as they are currently reported in the literature (**Figure 4.27**).

[7] Data management report available at: https://doi.org/10.5281/zenodo.7857828

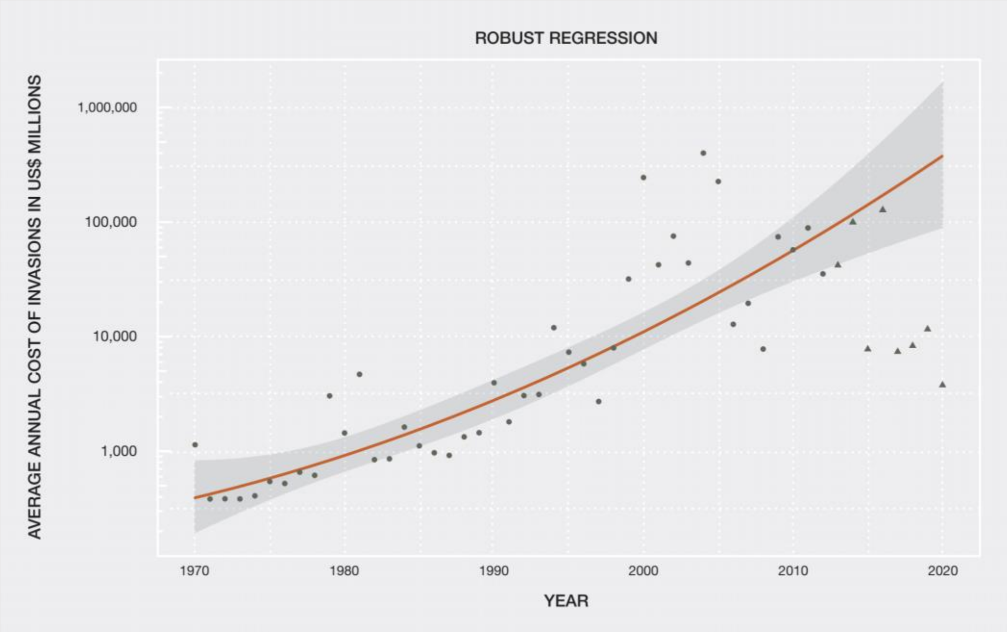


**Figure 4.25.** Temporal trend of global invasion costs (in millions of 2017 US$) between 1970 and 2019. A model prediction approach based on an Ordinary Least Square (OLS) regression was used in order to take into account (i) the dynamic nature of costs, (ii) the time lags between the real occurrence of the costs and their reporting in the literature (called "publication delay" hereafter), (iii) the heteroscedastic and temporally auto-correlated nature of cost data, and (iv) the effects of potential outliers in the cost estimates. The model was calibrated and fitted with at least 75 per cent of cost data completeness. All methodological details necessary for the rationale behind model selection as well as for obtaining this figure are presented in Diagne, Leroy et al. (2021), Leroy et al. (2022). Data management report available at: https://doi.org/10.5281/zenodo.7857828

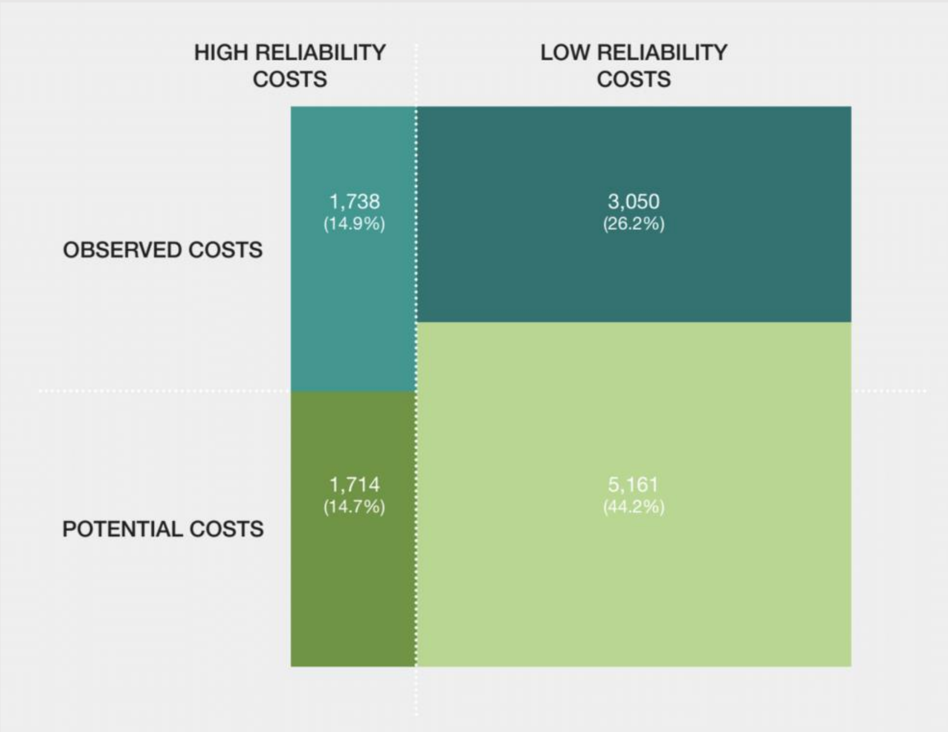


**Figure 4.26.** The proportion of costs in the InvaCost database according to their implementation and reliability. Numbers in the square represent the total cost in US$ billion, and the corresponding percentage of the whole in parentheses. All costs have been standardized in equivalent 2017

US$ (Diagne, Leroy, et al., 2020 for methodological details). InvaCost displays over 13,000 individual costs (at the time of writing this report), each described with 64 variables characterizing the record, the study, the typology of the economic cost and the invasive alien species. Among these, two are of major importance: implementation, i.e., whether the costs are actually observed or extrapolated and predicted (called "potential") and whether the original methodology led to a classification into either high or low reliability. The choice of these two variables dictates the number of costs accounted for in different studies, the resulting final global estimate and its overall robustness. This chapter only considers the most robust subset of InvaCost, the costs that are simultaneously observed and of high reliability (upper left square, less than 15 per cent of all available data). Note that this figure represents data recorded in the latest version of the InvaCost database available at the time of writing this report, and the proportions displayed here are likely to evolve as the database is updated over time. All cost information are regularly updated (Leroy et al., 2021).

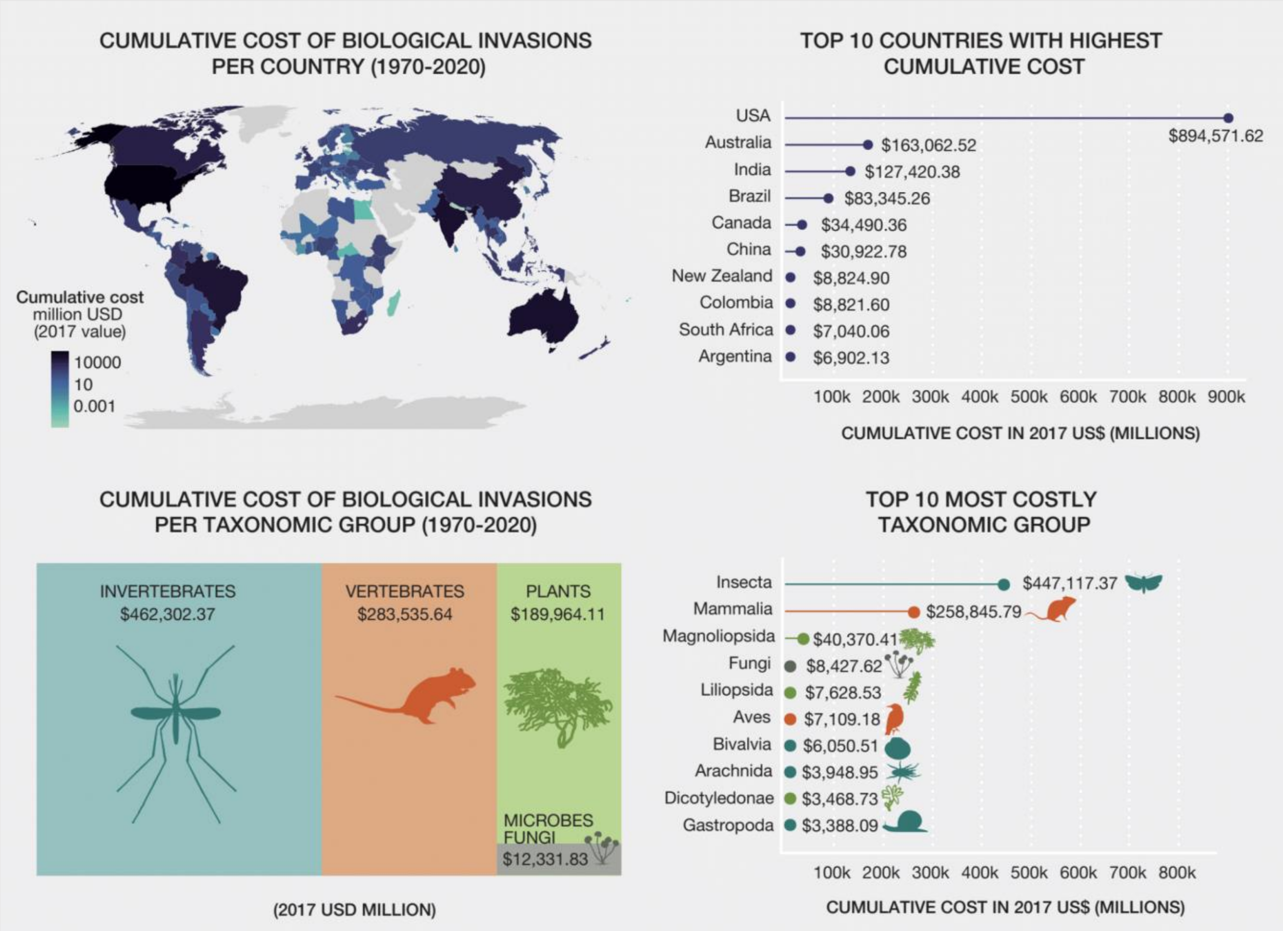


**Figure 4.27.** Synthesis of cumulative economic costs of biological invasions.[8] As available in the literature and standardized in the InvaCost database (latest version 4.0 available at the time of writing this report): for all countries in the world (top left), the 10 countries with the highest cumulative costs (top right) and the four major taxonomic groups (bottom left) as well as the ten costliest taxa (bottom right). All costs have been standardized in equivalent 2017 US$ (Diagne, Leroy, et al. (2021) and Leroy et al. (2022) for methodological details) and only the most robust subset has been used here (**Figure 4.26**). Note that this figure represents data recorded in the latest version of the InvaCost database available at the time of writing this report, and the proportions

[8] The boundaries and names shown, and the designations used on the maps shown here do not imply official endorsement or acceptance by IPBES.

displayed here are likely to evolve as the database is updated over time. All cost information are regularly updated (Leroy et al., 2021 for the most up-to-date figures). Data management report available at: https://doi.org/10.5281/zenodo.8231570

**Most impacted categories of nature's contributions to people**

More than 66 per cent of documented impacts on nature's contributions to people are on the provision of food and feed (**Figure 4.28**). These include mainly decreases in crop and forest tree production caused by alien weeds, pests and pathogens (Fried et al., 2017; Kenis et al., 2017), but also the impact of invasive alien microbes on livestock (French, 2017) and the impact of invasive alien species on fisheries and aquaculture (Gozlan, 2017). Most invasive alien species cause negative impacts on provision of food and feed (748 species), on habitat creation and maintenance (255 species) and on provision of materials, companionship and labour (301 species). Invasive alien species also cause positive impacts on provision of food and feed (199 species), on medicinal, biochemical and genetic resources (83 species) and on the formation, protection and decontamination of soils and sediments (77 species).

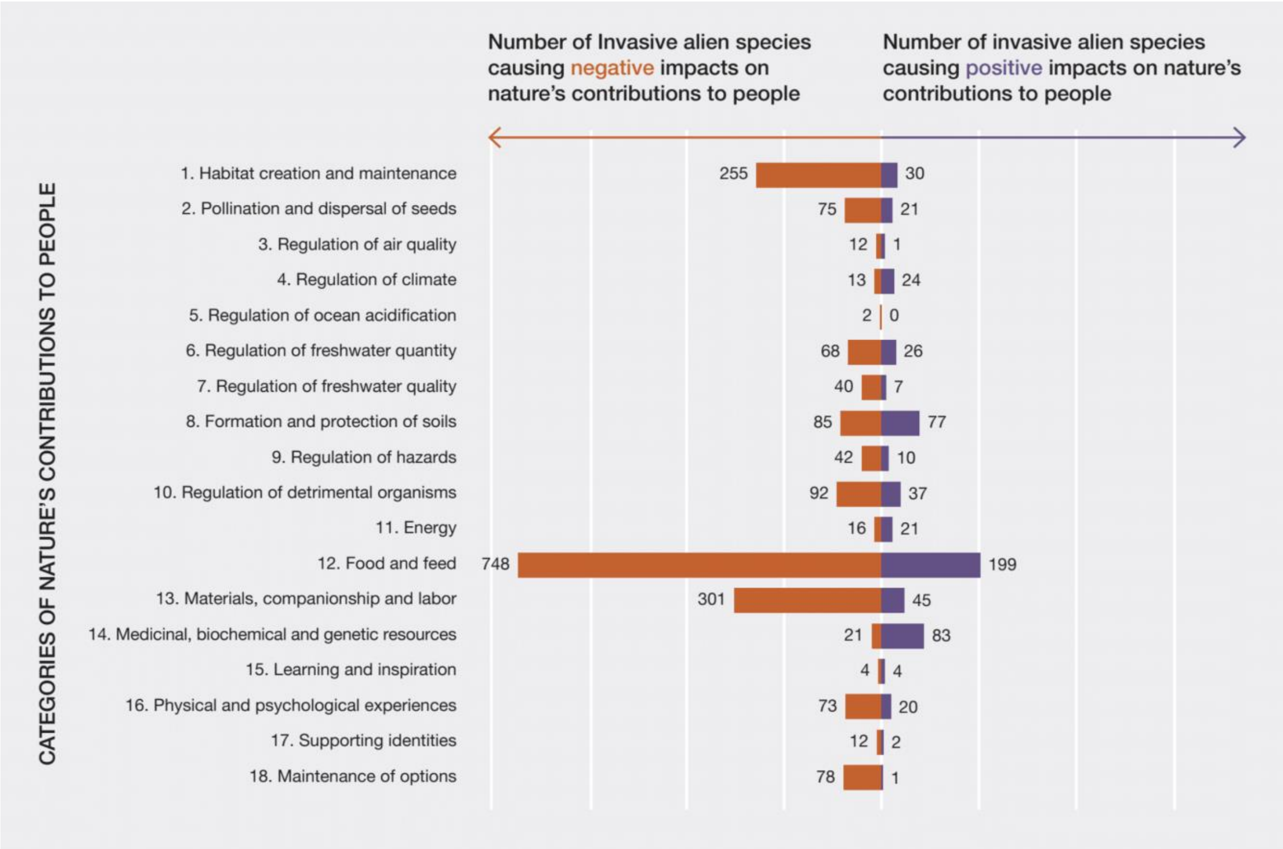


**Figure 4.28.** Documented numbers of invasive alien species causing negative and positive impacts on categories of nature's contributions to people. Positive and negative stacked bar charts do not imply that positive and negative impacts can be summed. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

**Conflict species causing both positive and negative impacts**

There are some invasive alien species that cause both positive and negative impacts on nature's contributions to people, which causes conflicts among different socioeconomic sectors as, for instance, the farming and conservation sectors (Vilà & Hulme, 2017). This duality makes the quantification of nature's contributions to people a challenge. Conflicting values are prominently found with respect to invasive alien trees which are seen as positive because they provide wood and contribute to carbon sequestration and thus to climate regulation; however, at the same time, many alien trees increase fire hazards (Castro-Díez et al., 2019) and decrease the recreational use of forests (Vaz et al., 2018; **Chapter 5**, **section 5.6.1.2**).

**Invasive alien species most often documented causing impacts on nature's contribution to people**

The top ten species that are most often documented to have negative impacts on nature's contributions to people comprise four plants, five invertebrates and a fish (**Table 4.14A**). *Pontederia crassipes* (water hyacinth) and many other aquatic plants have pervasive impacts on water quality and quantity, clog irrigation and draining ditches, and thereby interfere with boating and fishing (Brundu, 2015; Ueki et al., 1976). The plants *Reynoutria japonica* (Japanese knotweed) and *Impatiens glandulifera* (Himalayan balsam), and the tree *Robinia pseudoacacia* (black locust), which commonly invade central European habitats, cause impacts on soil quality and on pollination (Dassonville et al., 2011; Nienhuis et al., 2009). *Dreissena polymorpha* (zebra mussel), one of the most studied freshwater invertebrates, has negative impacts on nature's contributions to people by, for example, disrupting energy production (Ludyanskiy et al., 1993; Karatayev et al., 2005). Four invertebrates affect food and feed provision: *Solenopsis invicta* (red imported fire ant), *Bactrocera dorsalis* (Oriental fruit fly), *Chilo partellus* (spotted stem borer), and *Lissachatina fulica* (giant African land snail). *Cyprinus carpio* (common carp) is the invasive alien vertebrate with most documented impacts; it eats submerged vegetation and destroys hatching grounds for small native fishes, invertebrates, or other aquatic animals, changes the nutrient compositions in water through grubbing sediments (Matsuzaki et al., 2009), and spreads Koi herpesvirus to native carp populations that show higher mortality than introduced populations (Uchii et al., 2009).

**Table 4.14.** Top 10 invasive alien species with most documented negative and positive impacts on nature's contributions to people

The invasive alien species with most documented A) negative and B) positive impacts on nature's contributions to people. Note that this is not an indication of the global impact of these species, but of the number of cases found and analysed in this report. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

Plants:  Invertebrate: 

Vertebrate:  Microorganisms: 

| A) Negative impacts on nature's contributions to people | | |
|---|---|---|
| **Species** | **Taxa** | **Nature's contributions people (number of documented impacts)** |
| *Pontederia crassipes* (water hyacinth) |  | Energy (2); Food & feed (32); Freshwater quantity (19); Options (2); Physical experiences (4); Water quality (18) |
| *Solenopsis invicta* (red imported fire ant) |  | Biological processes (13); Energy (3); Food & feed (35); Learning (1); Materials (12); Options (4) |
| *Dreissena polymorpha* (zebra mussel) |  | Energy (17); Freshwater quantity (4); Materials (13); Medicinal (2); Ocean acidification (1); Options (8); Water quality (7) |
| *Bactrocera dorsalis* (Oriental fruit fly) |  | Food & feed (41) |
| *Impatiens glandulifera* (Himalayan balsam) |  | Biological processes (9); Freshwater quantity (4); Pollination & dispersal (5); Soils formation (22) |

| | | |
|---|---|---|
| *Robinia pseudoacacia* (black locust) | | Biological processes (13); Soils formation (27) |
| *Chilo partellus* (spotted stem borer) | | Food & feed (37) |
| *Lissachatina fulica* (giant African land snail) | | Food & feed (36) |
| *Reynoutria japonica* (Japanese knotweed) | | Soils formation (33) |
| *Cyprinus carpio* (common carp) | | Food & feed (28) |
| | | |
| **B) Positive impacts on nature's contributions to people** | | |
| **Species** | **Taxa** | **Nature's contributions people (number of documented impacts)** |
| *Solidago gigantea* (giant goldenrod) | | Climate (6); Soils formation (48) |
| *Robinia pseudoacacia* (black locust) | | Energy (6); Food & feed (10); Materials (2); Physical experiences (8); Soils formation (26) |
| *Acacia longifolia* (golden wattle) | | Climate (5); Freshwater quantity (3); Hazards (1); Soils formation (37) |
| *Impatiens glandulifera* (Himalayan balsam) | | Biological processes (4); Freshwater quantity (5); Pollination & dispersal (8); Soils formation (23) |
| *Reynoutria japonica* (Japanese knotweed) | | Climate (3); Pollination (3); Soils formation (32) |
| *Rosa rugosa* (rugosa rose) | | Biological processes (6); Climate (2); Hazards (1); Physical experiences (3); Soils formation (21) |
| *Prosopis juliflora* (mesquite) | | Energy (9); Food & feed (10); Habitat (2); Materials (6); Medicinal (3); Physical experiences (2) |
| *Acacia dealbata* (acacia bernier) | | Climate (4); Soils formation (23) |
| *Carpobrotus edulis* (hottentot fig) | | Air quality (1); Freshwater quantity (3); Hazards (2); Soils formation (15) |
| *Pontederia crassipes* (water hyacinth) | | Biological processes (4); Food & feed (5); Hazards (1); Materials (2); Medicinal (3); Water quality (2) |

The top ten invasive alien species that are most often documented to have positive impacts on nature's contributions to people are plants (**Table 4.14B**), all of which also cause negative impacts. For example, *Acacia longifolia* (golden wattle) and *Acacia dealbata* (acacia bernier) are N-fixing species that have been introduced to restore degraded soils but at the same time, their invasion modifies the structure of the habitats to be both beneficial or detrimental to people depending on their socioeconomic and cultural context (Kull et al., 2011). Similarly, *Prosopis juliflora* (mesquite) affects the availability of fodder for domestic livestock by reducing grassland area and grass cover (P. N. Joshi et al., 2009; Kohli et al., 2006; Timsina et al., 2011), but at the same time constitutes an important source of fuelwood (Dayal, 2007; Duenn et al., 2017), its stems can be used for fencing (D. Bartlett et al., 2018; Duenn et al., 2017), it can improve soil quality via biochar (D. Bartlett et al., 2018), and there are reports of people adapting to the use of plant parts for medicinal purposes (Duenn et al., 2017). The overwhelming negative impacts of *Prosopis juliflora* on nature's contributions to people are not offset by its positive impacts.

### 4.4.1.1. Islands vs. mainland

Despite the seminal and substantial body of literature on the threats and impacts of invasive alien species in remote islands, such as Hawaii, the Galapagos or New Zealand, only 12 per cent of the impacts on nature's contributions to people are documented on islands. The vast majority (76.4 per cent) of impacts on islands are negative (**Figure 4.29**) which is similar to the proportion of negative impacts on mainlands (79.3 per cent). Also, the affected categories of nature's contributions to people for which there are the most documented impacts are similar between islands and mainlands: namely on provision of food and feed (caused by 139 invasive alien species), provision of materials, companionship and labour (51 invasive alien species), and on habitat creation and maintenance (44 invasive alien species). The proportion of documented positive impacts is more important on islands than on mainlands, noticeably on food and feed (44.8 per cent on islands against 22.2 per cent on mainlands) and pollination and propagule dispersal (10.4 per cent on islands against 3 per cent on mainlands). On the contrary, on islands, the proportion of impacts on the formation, protection and decontamination of soils and sediments (17.5 per cent on islands against 35.8 per cent on mainlands), medicinal, biochemical and genetic resources (2.2 per cent on islands against 9.8 per cent on mainlands) are smaller than on mainlands. Biogeographic comparative analysis between homologous habitats in islands and mainland invaded by the same invasive alien species are necessary to identify the consistency in direction and intensity of their impacts on nature's contributions to people (D'Antonio & Dudley, 1995).

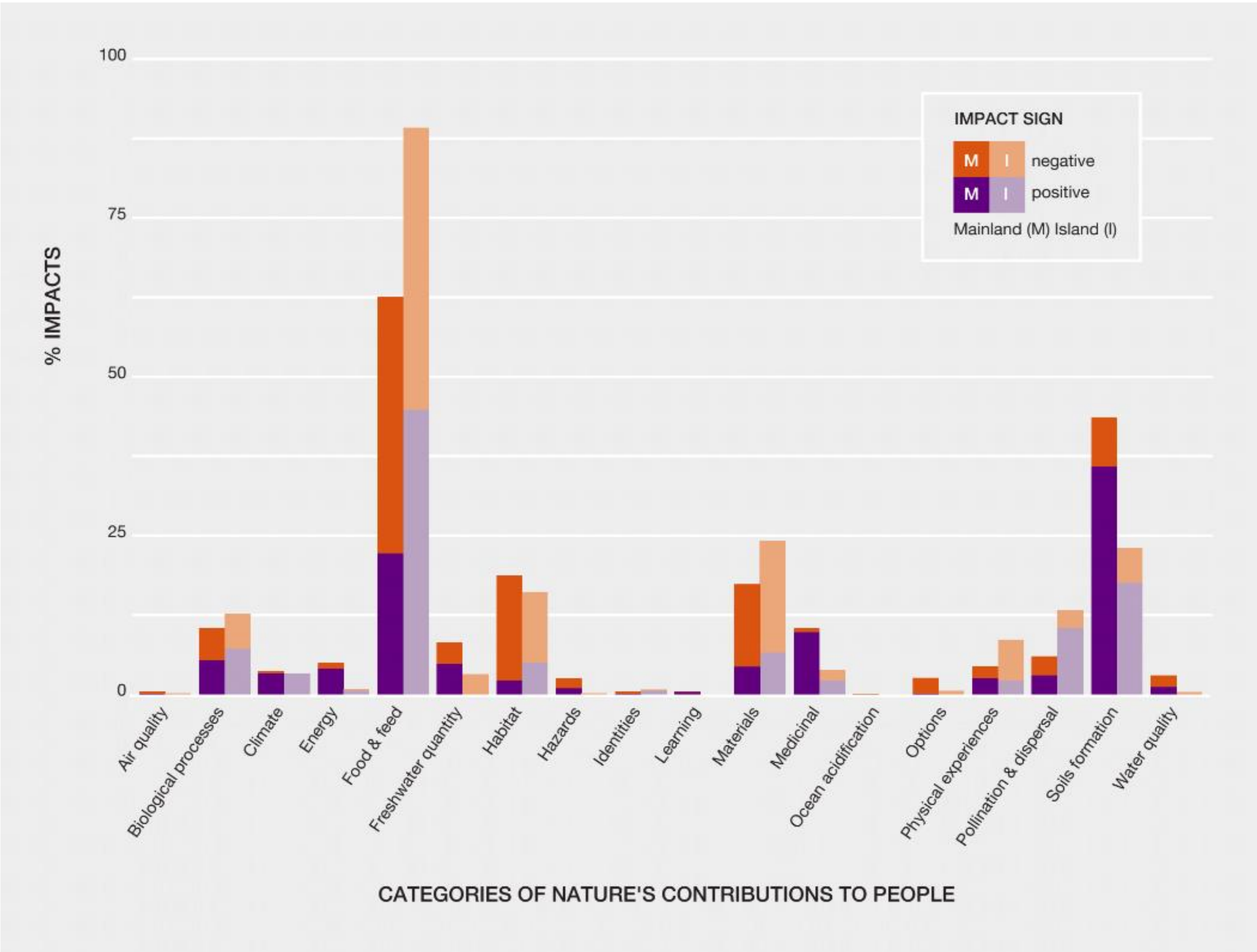


**Figure 4.29**. Negative and positive impacts on nature's contributions to people on mainland and on islands. This figure shows the percentage (y axis) of positive (bottom half of bar) and negative impacts (top half of bar) on islands and on mainland or unknown territories for each category of nature's contributions to people (x axis). Positive and negative stacked bar charts do not imply that

positive and negative impacts can be summed. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

#### 4.4.1.2. Protected areas

The SCOPE international programme on biological invasions indicated the need for research, monitoring (**Glossary**) and management of the impacts of invasive alien species in protected areas (Foxcroft, Pyšek, et al., 2013). However, a recent analysis has shown that the perceived threat in protected areas has worsened over time especially for plants (Foxcroft, Pyšek, et al., 2013; R. T. Shackleton et al., 2020). Five per cent of the documented impacts on nature's contributions to people occur in protected areas, with more positive (54.7 per cent) than negative (45.3 per cent) impacts. More than 50 per cent of the documented impacts in protected areas concern changes of the formation, protection and decontamination of soils and sediments. Other important impacts are on the provision of food and feed (13.2 per cent of the impacts on nature's contributions to people in protected areas), the regulation of freshwater quantity, location and timing (8.4 per cent) and regulation of detrimental organisms and biological processes (8.4 per cent). Notwithstanding, the importance of protected areas for their cultural, sometimes sacred value, there are no documented impacts on non-material nature's contributions to people such as impacts on learning and inspiration, physical and psychological experiences and supporting identities.

### 4.4.2. Documented impacts of invasive alien species on nature's contributions to people by realm

#### 4.4.2.1. Patterns of negative and positive impacts of invasive alien species on nature's contributions to people in the terrestrial realm

**Impacted units of analysis in the terrestrial realm**

There are many more documented negative impacts of invasive alien species on nature's contributions to people than positive impacts (3,424 against 1,103, respectively) in the terrestrial realm. Cultivated areas (approximately 33 per cent of impacts) and temperate and boreal forests (approximately 20 per cent of impacts) together account for more than half of all documented negative impacts of invasive alien species on nature's contributions to people. These are followed by urban/semi-urban areas, temperate grasslands, and tropical and subtropical dry and humid forests (8 to 10 per cent each). The remaining four units of analysis together constitute less than 20 per cent of all documented impacts. In the case of positive impacts, the largest proportion of documented impacts is from temperate and boreal forests (23 per cent), followed by temperate grassland (approximately 19 per cent). Cultivated areas, tropical and subtropical dry and humid forests, and Mediterranean woodlands, forests and scrub account for between 11 and 15 per cent each. The rest of the four terrestrial units of analysis together constitute less than one-fifth of all documented impacts. The predominance of certain units of analysis amongst documented impacts of invasive alien species on nature's contributions to people is more likely a reflection of information availability rather than actual impacts. For example, in a recent review of alien trees and their impacts on ecosystem services, Castro-Díez et al. (2019) found that the temperate and Mediterranean biomes were over-represented proportionate to their area, compared with other large regions of the world, such as Asia and Africa.

**Impacted categories of nature’s contributions to people in the terrestrial realm**

Negative impacts of invasive alien species on nature’s contributions to people are dominated by the categories of food and feed (40 per cent of documented impacts) followed by habitat creation and maintenance (approximately 20 per cent of documented impacts). Negative impacts on the category, formation, protection and decontamination of soils and sediments account for an additional 9 per cent of documented impacts, with all other categories together constituting less than 30 per cent of documented negative impacts (**Figure 4.30**). Positive impacts are dominated by impacts on the categories, formation, protection and decontamination of soils and sediments (38 per cent), food and feed (21 per cent), and medicinal, biochemical and genetic resources (approximately 10 per cent). The remaining categories of nature’s contributions to people together account for only 30 per cent of all documented positive impacts (**Figure 4.31**).

Negative impacts on particular categories of nature’s contributions to people predominate in certain units of analysis (**Figure 4.30**). For example, negative impacts on food and feed are prominent in cultivated areas (76 per cent of documented impacts, caused by 321 species). Negative impacts on food and feed are also a large proportion of total documented negative impacts in tropical and subtropical dry and humid forests (45 per cent of documented impacts caused by 55 species), tropical and subtropical savannas and grasslands (32 per cent of documented impacts caused by 49 species) and urban/semi-urban areas (about 30 per cent of documented impacts caused by 42 species).

Impacts on habitat creation and maintenance account for about 40 to 50 per cent of all documented negative impacts in deserts and xeric shrublands (50 per cent of documented impacts, caused by 29 species), temperate grasslands (43 per cent of documented impacts caused by 74 species), and tropical and subtropical savannas and grasslands (36 per cent of documented impacts caused by 31 species). So also, impacts on formation, protection and decontamination of soils and sediments constitute between a fifth to a fourth of all negative impacts in Mediterranean woodlands forests and scrub (27 per cent of documented impacts caused by 22 species), followed by temperate grasslands (20 per cent of documented impacts caused by 19 species), and temperate and boreal forests (19 per cent of documented impacts caused by 25 species).

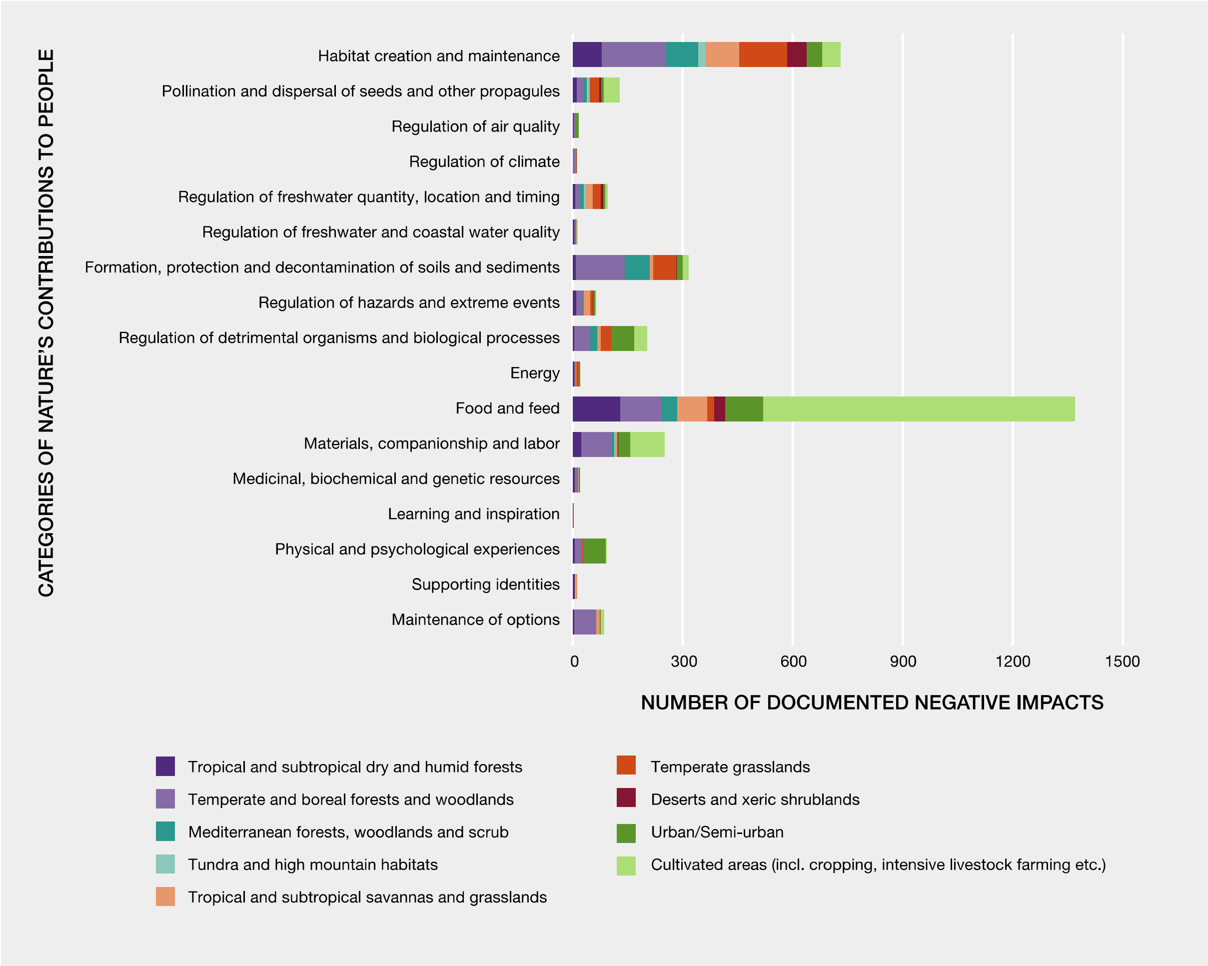


**Figure 4.30.** Documented number of negative impacts of invasive alien species (x axis) on categories of nature's contributions to people (y axis) across different terrestrial units of analysis. There are 3,424 documented negative impacts across all categories of nature's contributions to people in the terrestrial realm. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

As with negative impacts of invasive alien species, certain types of positive impacts on nature's contributions to people also predominate in particular units of analysis (**Figure 4.31**). Impacts on the category, formation, protection and decontamination of soils and sediments, outweigh positive impacts on all other categories of nature's contributions to people in Mediterranean woodlands forests and scrub (70 per cent of documented impacts; 14 species). Positive impacts on formation, protection and decontamination of soils and sediments also account for between a third to half of all documented impacts in temperate grassland (53 per cent of documented impacts, caused by 30 species), temperate and boreal forests (40 per cent of documented impacts, caused by 28 species), and in cultivated areas (34 per cent of documented impacts, caused by 23 species).

Impacts on the category food and feed, constitute around a quarter of all documented positive impacts in tropical and subtropical dry and humid forests (29 per cent of documented impacts, caused by 35 species), and temperate and boreal forests (24 per cent of documented impacts, caused by 32 species); they also account for almost a fifth of all documented positive impacts in temperate grasslands (18 per cent of documented impacts, caused by 21 species) and cultivated areas (18 per cent of documented impacts, caused by 18 species). Positive impacts on the category, medicinal, biochemical and genetic resources also make a sizeable contribution to documented positive impacts in tundra and high mountain habitats (45 per cent; of documented impacts, caused by 13 species), tropical and subtropical dry and humid forests (32 per cent of documented impacts, caused by 43 species), and cultivated areas (15 per cent of documented impacts, caused by 22 species).

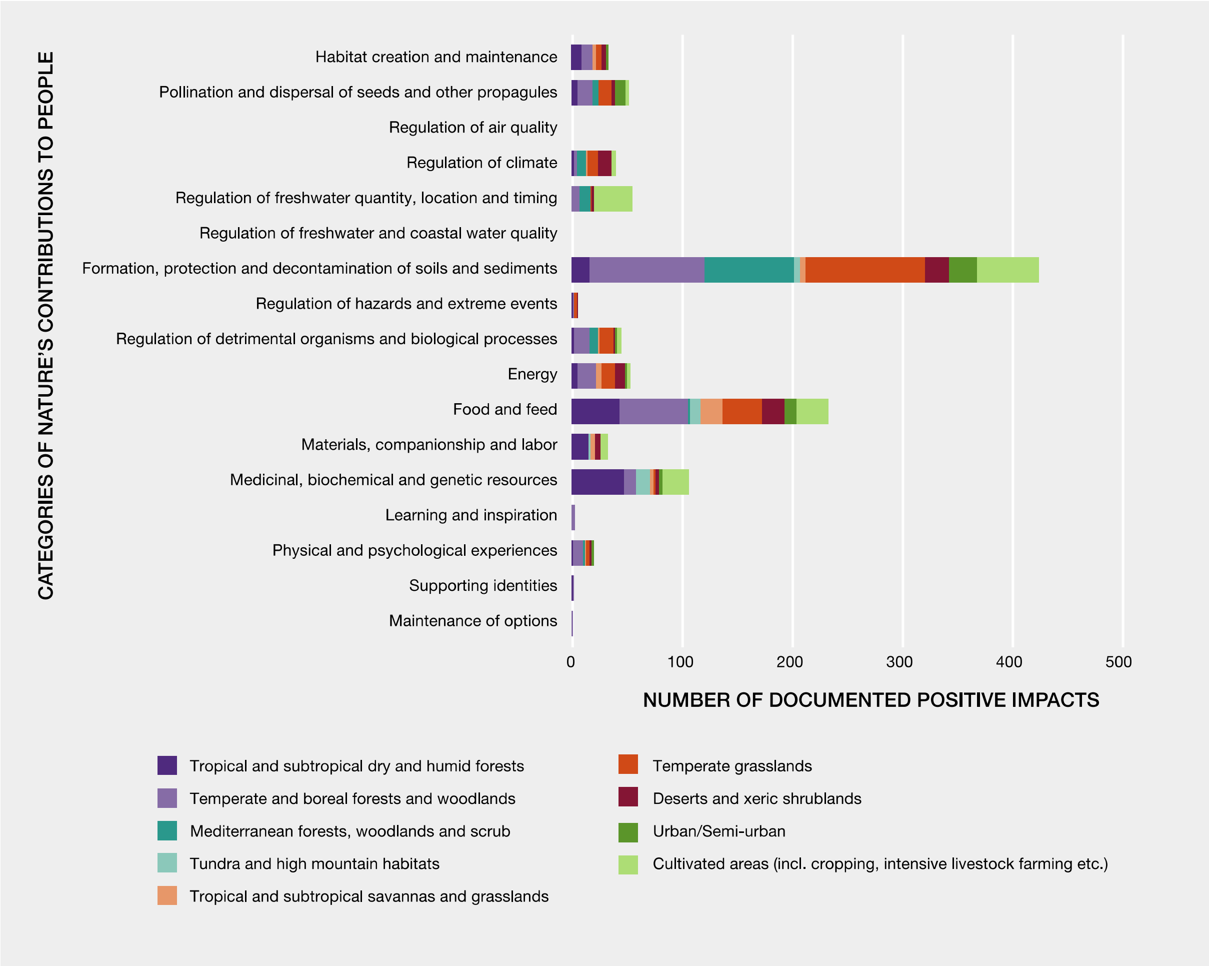


**Figure 4.31.** Documented number of positive impacts (x axis) of invasive alien species on categories of nature's contributions to people (y axis) across different terrestrial units of analysis. There are 1,103 documented positive impacts across all categories of nature's contributions to people in the terrestrial realm. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

**Invasive alien taxa most often documented causing impacts on nature's contributions to people in the terrestrial realm**

Plants is generally the invasive alien species taxonomic group that causes the most impacts (both positive and negative) on nature's contributions to people across all units of analysis (**Table 4.15**). Notable exceptions to this overall pattern occur in cultivated areas and in Mediterranean woodlands, forests and scrub. In cultivated areas, the top 10 species of invasive alien species causing negative impacts are invertebrate crop pests (the top five of which are *Spodoptera frugiperda* (fall armyworm), *Bactrocera dorsalis* (Oriental fruit fly), *Solenopsis invicta* (red imported fire ant), *Chilo partellus* (spotted stem borer), and *Phenacoccus manihoti* (cassava mealybug)). *Spodoptera frugiperda* alone accounts for four to six per cent of maize losses in North and South America and Sub-Saharan Africa (Savary et al., 2019), though yield losses ranging from 10 per cent up to 58 per cent have been estimated across different countries in Africa (**Box 4.18**; **Table 4.26**). Globally, total crop losses (from all pests and pathogens combined) are estimated at 20 to 30 per cent, based on a global survey of crops that together account for about half of human calorie intake (Savary et al., 2019). A large proportion of these total crop losses is due to insect and mite pests, 30 to 45 per cent of which are alien invasive arthropods, as estimated across several large crop-growing countries of the world (Pimentel et al., 2001).

In Mediterranean woodlands, forests and scrub, seven of the top 10 invasive alien species are microbes and include five species of fungi, a bacterium (*Xylella fastidiosa* (Pierce's disease of grapevines)), and an oomycete (*Phytophthora cinnamomi* (Phytophthora dieback)). Negative impacts of these microbes on nature's contributions to people include, more specifically, impacts on habitat creation and maintenance. For example, *Ceratocystis platani* (canker stain of plane), a canker-causing fungus thought to have been accidentally introduced to Europe from North America in the first half of the twentieth century, damages the iconic *Platanus orientalis* (plane), especially in Greece (Tsopelas et al., 2017). Other significant examples of negative impacts are impacts on the provision of food and feed. *Cryphonectria parasitica* (blight of chestnut), which has devastated native North American chestnut populations following its accidental introduction to the United States in the early twentieth century (Anagnostakis, 1987), is also a significant pest in Europe, where it threatens fruit and wood production from the European chestnut (EFSA PLH Panel (EFSA Panel on Plant Health), 2014). Likewise, recently discovered (in 2013) olive quick decline syndrome (OQDS), caused by *Xylella fastidiosa* has caused significant losses to the economically and culturally important olive crop in Italy's main olive growing region (White et al., 2017).

Most invertebrates appearing in the top 10 invasive alien species by unit of analysis are associated with negative impacts on nature's contributions to people. However, exceptions are the positive impacts on pollination, and food and feed by *Apis mellifera* (European honeybee) in temperate and boreal forests, Mediterranean woodland forest and scrub, and cultivated areas. In the United States, for example, the pollination of crops by *Apis mellifera* is in the order of tens of billions of US$ annually (Pejchar & Mooney, 2009). *Apis mellifera* has also been observed to pollinate the culturally significant Hawaiian endemic tree, *Meterosideros polymorpha* (`Ohi'a), and could play an important role in the future, as species assemblages increasingly change as a result of species invasions, habitat fragmentation, and climate change (Cortina et al., 2019). However, in Latin America, *Apis mellifera* has hybridized with the aggressive Africanized honeybee, and threatens human health (Pejchar & Mooney, 2009). Another invertebrate that was introduced as a pollinator of cultivated plants to many regions of the globe is *Bombus terrestris* (bumble bee). Although it is now an invasive alien species, its use as a pollinator continues, though it is regulated (e.g., in Japan; Goka, 2010). In some cases, invasive alien plants also support pollination providing a reliable source of nectar and pollen at times of the year when agricultural landscapes are otherwise not providing sufficient resources to maintain pollinator populations (Hirsch et al., 2020).

The regulation of detrimental organisms and biological processes is another category of nature's contributions to people that is positively impacted by an invertebrate, e.g., by *Nematus oligospilus* (willow sawfly) in urban/semiurban areas. This species was unintentionally introduced to Australia and New Zealand as a pest of introduced willows (Caron et al., 2014). It is therefore perceived as a beneficial species, since willows are detrimental to riparian and aquatic ecosystems (Bruzzese & McFadyen, 2006).

Some species cause both negative and positive impacts on nature's contributions to people, even within the same unit of analysis. *Prosopis* spp. (mesquite) are an example of this in deserts and xeric shrublands. Positive impacts include the provision of fuelwood, shade, and fodder in the form of pods (S. E. Shackleton & Shackleton, 2018; **Box 4.9**); negative impacts include depletion of groundwater (Dzikiti et al., 2013), a reduction in grazing resources, and damage caused to certain livestock from consumption of pods (Obiri, 2011; **Box 4.9**). *Prosopis juliflora*, *Prosopis pallida*, *Prosopis glandulosa*, *Prosopis chilensis*, and *Prosopis velutina* (collectively known as mesquite) have been introduced across the globe for the potential benefits they provide to people; however, with their spread in introduced regions, the negative impacts of *Prosopis* spp. come into conflict with their positive impacts, creating contradictions in how they are perceived by different stakeholders (R. T. Shackleton et al., 2014; **Box 4.9**).

Some species or taxa cause impacts on nature's contributions to people across multiple units of analysis. One example is the genus, *Acacia*, with different species - *Acacia dealbata* (acacia bernier), *Acacia mearnsii* (black wattle), and *Acacia saligna* (coojong) - causing positive impacts on nature's contributions to people across several different units of analysis. These positive impacts (on formation, protection and decontamination of soils and sediments, climate regulation, energy, and materials, companionship and labour (Lorenzo et al., 2010; Potgieter et al., 2019; C. M. Shackleton et al., 2007) align with a recent global review of the genus *Acacia* and its impacts, which found positive impacts on climate regulation, soil fertility and soil erosion control (Castro-Díez et al., 2021). However, these findings are at odds with other work highlighting the negative impacts of *Acaciae* on various categories of nature's contributions to people, especially regulation of freshwater quantity, location and timing, and regulation of hazards and extreme events; (Le Maitre et al., 2011). Although *Acaciae* are associated with negative impacts on nature's contributions to people in the impact database developed through this chapter[9] as well, their documented negative impacts do not rank amongst the top 10 species by units of analysis.

**Table 4.15.** Main invasive alien species impacting nature's contributions to people in the terrestrial realm

The top 10 (by number of documented impacts) invasive alien species causing negative and positive impacts on nature's contributions to people in the terrestrial realm by the affected units of analysis. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

Plants:  Invertebrate: 

Vertebrate:  Microorganisms: 

| Unit of Analysis | Invasive alien species with negative impacts on nature's contributions to people | | | Invasive alien species with positive impacts on nature's contributions to people | | |
|---|---|---|---|---|---|---|
| | **Taxa** | **Species** | **# documented impacts** | **Taxa** | **Species** | **# documented impacts** |
| Temperate and boreal forests and woodlands |  | *Lymantria dispar* (gypsy moth) | 26 |  | *Solenopsis invicta* (red imported fire ant) | 11 |
| | | *Solenopsis invicta* (red imported fire ant) | 25 |  | *Impatiens glandulifera* (Himalayan balsam) | 26 |
| |  | *Phytophthora ramorum* (sudden oak death) | 36 | | *Solidago gigantea* (giant goldenrod) | 15 |
| | | *Hymenoscyphus fraxineus* (ash dieback) | 26 | | *Reynoutria japonica* (Japanese knotweed) | 11 |
| | | *Fusarium circinatum* (pitch canker) | 17 | | *Microstegium vimineum* (Nepalese browntop) | 6 |

[9] Data management report available at: https://doi.org/10.5281/zenodo.5766069

| Unit of Analysis | Invasive alien species with negative impacts on nature’s contributions to people | | | Invasive alien species with positive impacts on nature’s contributions to people | | |
|---|---|---|---|---|---|---|
| | **Taxa** | **Species** | # documented impacts | **Taxa** | **Species** | # documented impacts |
| | | *Reynoutria* spp. (knotweed) | 19 | | *Rubus ulmifolius* (elmleaf blackberry) | 6 |
| | | *Impatiens glandulifera* (Himalayan balsam) | 18 | | *Elaeagnus umbellata* (autumn olive) | 5 |
| | | *Reynoutria japonica* (Japanese knotweed) | 17 | | *Lonicera japonica* (Japanese honeysuckle) | 5 |
| | | *Solidago gigantea* (giant goldenrod) | 15 | | *Impatiens parviflora* (small balsam) | 4 |
| | | *Quercus rubra* (northern red oak) | 14 | | *Prunus laurocerasus* (cherry laurel) | 4 |
| Cultivated areas (incl. cropping, intensive livestock farming etc.) | | *Spodoptera frugiperda* (fall armyworm) | 50 | | *Apis mellifera* (European honeybee) | 3 |
| | | *Bactrocera dorsalis* (Oriental fruit fly) | 41 | | *Reynoutria japonica* (Japanese knotweed) | 20 |
| | | *Solenopsis invicta* (red imported fire ant) | 41 | | *Solidago gigantea* (giant goldenrod) | 10 |
| | | *Chilo partellus* (spotted stem borer) | 37 | | *Centaurea stoebe* (spotted knapweed) | 3 |
| | | *Phenacoccus manihoti* (cassava mealybug) | 33 | | *Cortaderia selloana* (pampas grass) | 3 |
| | | *Liriomyza trifolii* (American serpentine leafminer) | 24 | | *Cucumis myriocarpus* (gooseberry gourd) | 3 |
| | | *Prostephanus truncatus* (larger grain borer) | 17 | | *Phalaris aquatica* (bulbous canarygrass) | 3 |
| | | *Liriomyza sativae* (vegetable leaf miner) | 12 | | *Campanula rapunculoides* (creeping bellflower) | 2 |
| | | *Frankliniella occidentalis* | 10 | | *Cenchrus ciliaris* (buffel grass) | 2 |

| **Unit of Analysis** | **Invasive alien species with negative impacts on nature's contributions to people** | | | **Invasive alien species with positive impacts on nature's contributions to people** | | |
|---|---|---|---|---|---|---|
| | **Taxa** | **Species** | **# documented impacts** | **Taxa** | **Species** | **# documented impacts** |
| | | (western flower thrips) | | | | |
| | | *Rastrococcus invadens* (fruit tree mealybug) | 10 | | *Columba livia* (pigeons) | 10 |
| Deserts and xeric shrublands | | *Bromus tectorum* (downy brome) | 18 | | *Carpobrotus* spp. (icelplant) | 8 |
| | | *Cenchrus ciliaris* (buffel grass) | 14 | | *Prosopis glandulosa* (honey mesquite) | 4 |
| | | *Eragrostis lehmanniana* (Lehmann lovegrass) | 5 | | *Bromus tectorum* (downy brome) | 3 |
| | | *Prosopis* spp. (mesquite) | 5 | | *Cirsium arvense* (creeping thistle) | 2 |
| | | *Erodium cicutarium* (common storksbill) | 4 | | *Erodium cicutarium* (common storksbill) | 2 |
| | | *Tamarix ramosissima* (saltcedar) | 3 | | *Prosopis alba* (white carob tree) | 2 |
| | | *Acacia longifolia* (golden wattle) | 2 | | *Aerva javanica* (kapok bush) | 1 |
| | | *Hilaria belangeri* (curly mesquite) | 2 | | *Carpobrotus acinaciformis* (Eland's sour-fig) | 1 |
| | | *Juniperus osteosperma* (Utah juniper) | 2 | | *Casuarina cunninghamiana* (Australian beefwood) | 1 |
| | | *Camelus* spp. (camels) | 3 | | *Cenchrus ciliaris* (buffel grass) | 1 |
| Tropical and subtropical dry and humid forests | | *Lissachatina fulica* (giant African land snail) | 36 | | *Falcataria falcata* (Moluccan albizia) | 7 |
| | | *Laevicaulis alte* (tropical leatherleaf slug) | 11 | | *Fraxinus uhdei* (tropical ash) | 7 |
| | | *Solenopsis invicta* (red imported fire ant) | 7 | | *Spathodea campanulata* (African tulip tree) | 5 |
| | | *Deroceras reticulatum* (grey field slug) | 5 | | *Cinchona pubescens* (quinine tree) | 4 |

| Unit of Analysis | Invasive alien species with negative impacts on nature's contributions to people | | | Invasive alien species with positive impacts on nature's contributions to people | | |
|---|---|---|---|---|---|---|
| | **Taxa** | **Species** | # documented impacts | **Taxa** | **Species** | # documented impacts |
| | | *Hypogeococcus* spp. (mealybug) | 4 | | *Decalobanthus peltatus* (merremia) | 4 |
| | | *Wasmannia auropunctata* (little fire ant) | 4 | | *Salix fragilis* (crack willow) | 4 |
| |  | *Phytophthora ramorum* (sudden oak death) | 5 | | *Cedrela odorata* (Spanish cedar) | 3 |
| |  | *Syzygium jambos* (rose apple) | 5 | | *Gleditsia triacanthos* (honey locust) | 3 |
| | | *Ageratum conyzoides* (billy goat weed) | 4 | | *Ligustrum lucidum* (broad-leaf privet) | 3 |
| | | *Jasminum fluminense* (Brazilian jasmine) | 4 | | *Pteridium aquilinum* (bracken) | 3 |
| Temperate Grasslands |  | *Rosa rugosa* (rugosa rose) | 17 |  | *Rosa rugosa* (rugosa rose) | 36 |
| | | *Reynoutria japonica* (Japanese knotweed) | 12 | | *Solidago gigantea* (giant goldenrod) | 29 |
| | | *Bromus tectorum* (downy brome) | 10 | | *Genista aetnensis* (Mount Etna broom) | 11 |
| | | *Poa pratensis* (smooth meadow-grass) | 10 | | *Reynoutria japonica* (Japanese knotweed) | 8 |
| | | *Solidago canadensis* (Canadian goldenrod) | 10 | | *Amorpha fruticosa* (false indigo-bush) | 7 |
| | | *Solidago gigantea* (giant goldenrod) | 10 | | *Acacia dealbata* (acacia bernier) | 6 |
| | | *Impatiens glandulifera* (Himalayan balsam) | 9 | | *Heracleum pubescens* (Sosnowskyi's hogweed) | 5 |
| | | *Senecio inaequidens* (South African ragwort) | 9 | | *Impatiens glandulifera* (Himalayan balsam) | 5 |
| | | *Solidago spp.* (goldenrod) | 9 | | *Brassica nigra* (black mustard) | 4 |

| Unit of Analysis | Invasive alien species with negative impacts on nature's contributions to people | | | Invasive alien species with positive impacts on nature's contributions to people | | |
|---|---|---|---|---|---|---|
| | Taxa | Species | # documented impacts | Taxa | Species | # documented impacts |
| | | *Bothriochloa ischaemum* (yellow bluestem) | 7 | | *Columba livia* (pigeons) | 10 |
| Mediterranean forests, woodlands and scrub | | *Xylella fastidiosa* (Pierce's disease of grapevines) | 15 | | *Carpobrotus* spp. (icelplant) | 27 |
| | | *Ceratocystis platani* (canker stain of plane) | 13 | | *Acacia dealbata* (acacia bernier) | 21 |
| | | *Seiridium cardinale* (cypress canker) | 11 | | *Genista aetnensis* (Mount Etna broom) | 6 |
| | | *Phytophthora cinnamomi* (Phytophthora dieback) | 10 | | *Platanus ×hispanica* (London planetree) | 6 |
| | | *Cryphonectria parasitica* (blight of chestnut) | 9 | | *Reynoutria ×bohemica* (Bohemian knotweed) | 6 |
| | | *Sphaeropsis sapinea* (Sphaeropsis blight) | 9 | | *Elaeagnus umbellate* (autumn olive) | 4 |
| | | *Heterobasidion irregulare* (conifer-base polypore) | 5 | | *Impatiens glandulifera* (Himalayan balsam) | 4 |
| | | *Carpobrotus* spp. (icelplant) | 10 | | *Lonicera maackii* (Amur honeysuckle) | 4 |
| | | *Lonicera maackii* (Amur honeysuckle) | 10 | | *Celastrus orbiculatus* (Asiatic bittersweet) | 2 |
| | | *Arundo donax* (giant reed) | 5 | | *Phalaris aquatica* (bulbous canarygrass) | 2 |
| Tropical and subtropical savannas and grasslands | | *Centaurea solstitialis* (yellow starthistle) | 16 | | *Acacia mearnsii* (black wattle) | 2 |
| | | *Elaeagnus umbellata* (autumn olive) | 12 | | *Cenchrus clandestinus* (Kikuyu grass) | 1 |
| | | *Imperata cylindrica* (cogon grass) | 8 | | *Cenchrus geniculatus* (spiny burrgrass) | 1 |
| | | *Melia azedarach* (chinaberry) | 7 | | *Centaurea solstitialis* (yellow starthistle) | 1 |

| Unit of Analysis | Invasive alien species with negative impacts on nature's contributions to people | | | Invasive alien species with positive impacts on nature's contributions to people | | |
|---|---|---|---|---|---|---|
| | Taxa | Species | # documented impacts | Taxa | Species | # documented impacts |
| | | *Melinis minutiflora* (molasses grass) | 7 | | *Eragrostis curvula* (weeping lovegrass) | 1 |
| | | *Ligustrum sinense* (Chinese privet) | 6 | | *Hyparrhenia hirta* (coolatai grass) | 1 |
| | | *Nandina domestica* (nandina) | 6 | | *Hyparrhenia rufa* (jaragua grass) | 1 |
| | | *Triadica sebifera* (Chinese tallow tree) | 6 | | *Koelreuteria elegans* subsp. *formosana* (flamegold) | 1 |
| | | *Biancaea decapetala* (Mysore thorn) | 5 | | *Medicago minima* (small medick) | 1 |
| | | *Holcus lanatus* (common velvet grass) | 5 | | *Bubalus bubalis* (Asian water buffalo) | 4 |
| Tundra and High Mountain habitats | | *Pinus mugo* (mountain pine) | 6 | | *Pinus mugo* (mountain pine) | 5 |
| | | *Bromus tectorum* (downy brome) | 4 | | *Eucalyptus globulus* (Tasmanian blue gum) | 2 |
| | | *Bromus inermis* (awnless brome) | 2 | | *Artemisia absinthium* (wormwood) | 1 |
| | | *Linaria vulgaris* (common toadflax) | 2 | | *Capsella bursa-pastoris* (shepherd's purse) | 1 |
| | | *Melilotus albus* (honey clover) | 2 | | *Cenchrus clandestinus* (Kikuyu grass) | 1 |
| | | *Agropyron cristatum* (crested wheatgrass) | 1 | | *Erodium cicutarium* (common storksbill) | 1 |
| | | *Bromus hordeaceus* (soft brome) | 1 | | *Hypericum perforatum* (St John's wort) | 1 |
| | | *Bromus japonicus* (Japanese brome) | 1 | | *Malva neglecta* (common mallow) | 1 |
| | | *Cenchrus clandestinus* (Kikuyu grass) | 1 | | *Malva parviflora* (pink cheeseweed) | 1 |
| | | *Erodium cicutarium* (common storksbill) | 1 | | *Matricaria chamomilla* (common chamomile) | 1 |

| Unit of Analysis | Invasive alien species with negative impacts on nature's contributions to people | | | Invasive alien species with positive impacts on nature's contributions to people | | |
|---|---|---|---|---|---|---|
| | **Taxa** | **Species** | # documented impacts | **Taxa** | **Species** | # documented impacts |
| Urban/Semi-urban |  | *Lissachatina fulica* (giant African land snail) | 32 |  | *Trichocorixa verticalis* (water boatman) | 2 |
| | | *Wasmannia auropunctata* (little fire ant) | 12 | | *Bombus terrestris* (bumble bee) | 1 |
| | | *Laevicaulis alte* (tropical leatherleaf slug) | 9 | | *Nematus oligospilus* (willow sawfly) | 1 |
| | | *Monomorium pharaonis* (pharaoh ant) | 8 |  | *Lupinus polyphyllus* (garden lupin) | 8 |
| | | *Anoplolepis gracilipes* (yellow crazy ant) | 7 | | *Symphyotrichum lanceolatum* (narrow-leaved michaelmas daisy) | 7 |
| | | *Paratrechina fulva* (tawny crazy ant) | 5 | | *Impatiens glandulifera* (Himalayan balsam) | 4 |
| |  | *Ceratocystis platani* (canker stain of plane) | 5 | | *Paspalum distichum* (knotgrass) | 2 |
| |  | *Impatiens glandulifera* (Himalayan balsam) | 12 | | *Acacia saligna* (coojong) | 1 |
| | | *Lupinus polyphyllus* (garden lupin) | 7 | | *Agrostis alba* (redtop) | 1 |
| | | *Heracleum pubescens* (Sosnowskyi's hogweed) | 6 |  | *Columba livia* (pigeons) | 10 |

### 4.4.2.2. Patterns of negative and positive impacts of invasive alien species on nature's contributions to people in the inland waters realm

#### Impacted units of analysis in the inland waters realm

In inland waters, negative impacts of invasive alien species on nature's contributions to people outnumber positive impacts by a ratio of 4:1, with 600 documented negative impacts compared with only 145 documented positive impacts. About 70 per cent of all documented impacts, both negative and positive, on nature's contributions to people in inland waters are from inland surface waters and water bodies/freshwater; the remainder are found to almost equal measure in wetlands, and in aquaculture areas (**Figures 4.32** and **4.33**).

### Impacted categories of nature's contributions to people in inland waters

In inland waters, invasive alien species' negative impacts on food and feed predominate, and constitute about 50 per cent of all documented negative impacts on nature's contributions to people in this realm (**Figure 4.32**). In aquaculture areas, about 90 per cent of negative impacts are on food and feed (caused by 28 species); in inland surface waters/waterbodies 55 per cent of negative impacts are on food and feed (caused by 82 species). Other sizeable negative impacts of invasive alien species on nature's contributions to people are on habitat creation and maintenance in wetlands (44 per cent of documented impacts, 25 species), and on freshwater quantity (10 per cent of documented impacts; 16 species), and water quality (12 per cent; 18 species), in inland surface waters/waterbodies.

Impacts on the category food and feed also account for the majority (60 per cent) of all documented positive impacts in inland waters (**Figure 4.33**). Impacts on food and feed constitute 95 per cent of all positive impacts in aquaculture areas (caused by 15 species) and about 60 per cent in inland surface waters/waterbodies (caused by 31 species). Positive impacts on the category formation, protection and decontamination of soils and sediments, constitute almost 50 per cent of all documented impacts in wetlands, caused by five species. Other documented positive impacts are on physical and psychological experiences, water quality, and regulation of biological processes (about 10 per cent of documented impacts each), in inland surface waters/waterbodies.

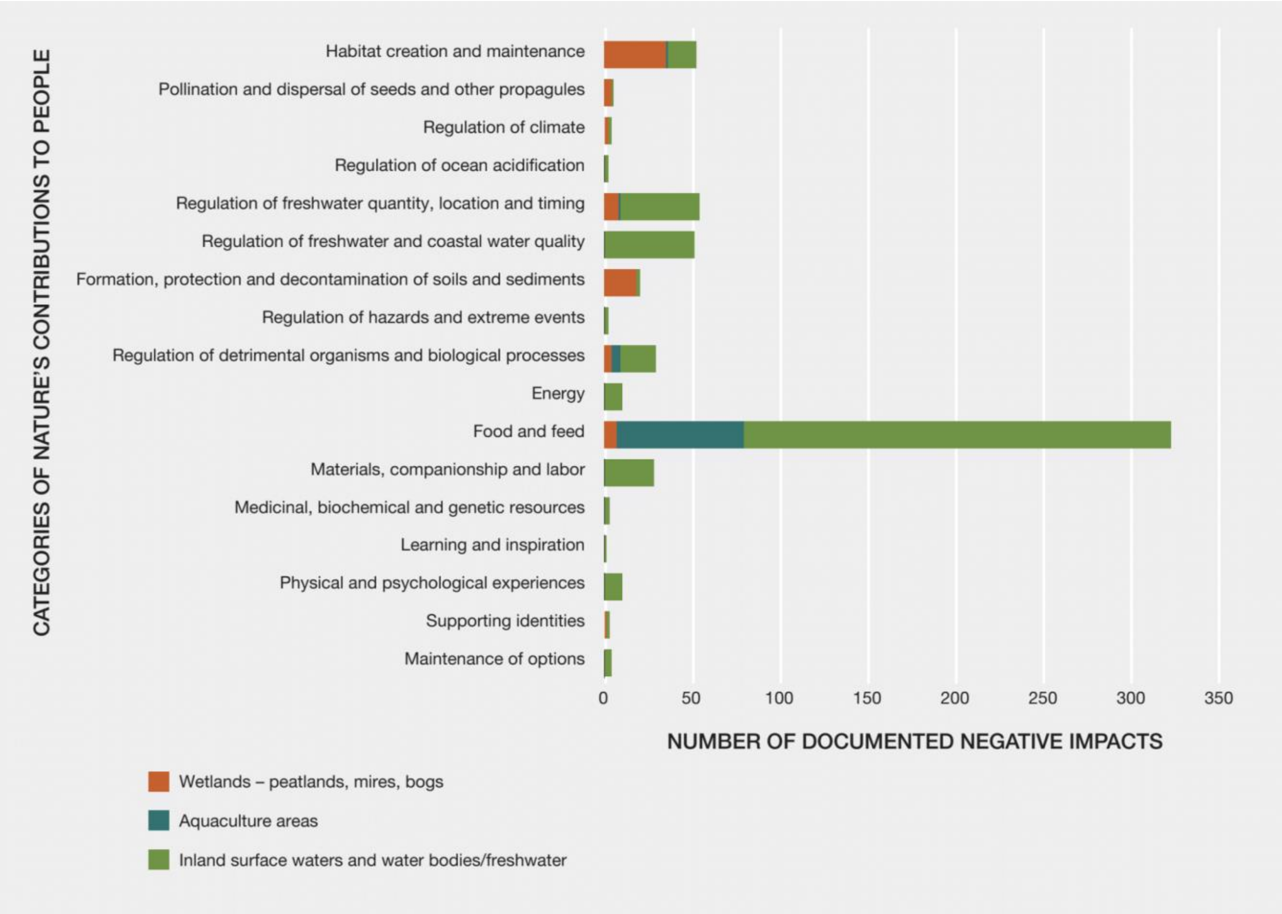


**Figure 4.32.** Documented negative impacts (x axis) of invasive alien species on categories of nature's contributions to people (y axis) in the inland waters realm. There are 600 documented negative impacts across all categories of nature's contributions to people in the inland waters realm. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

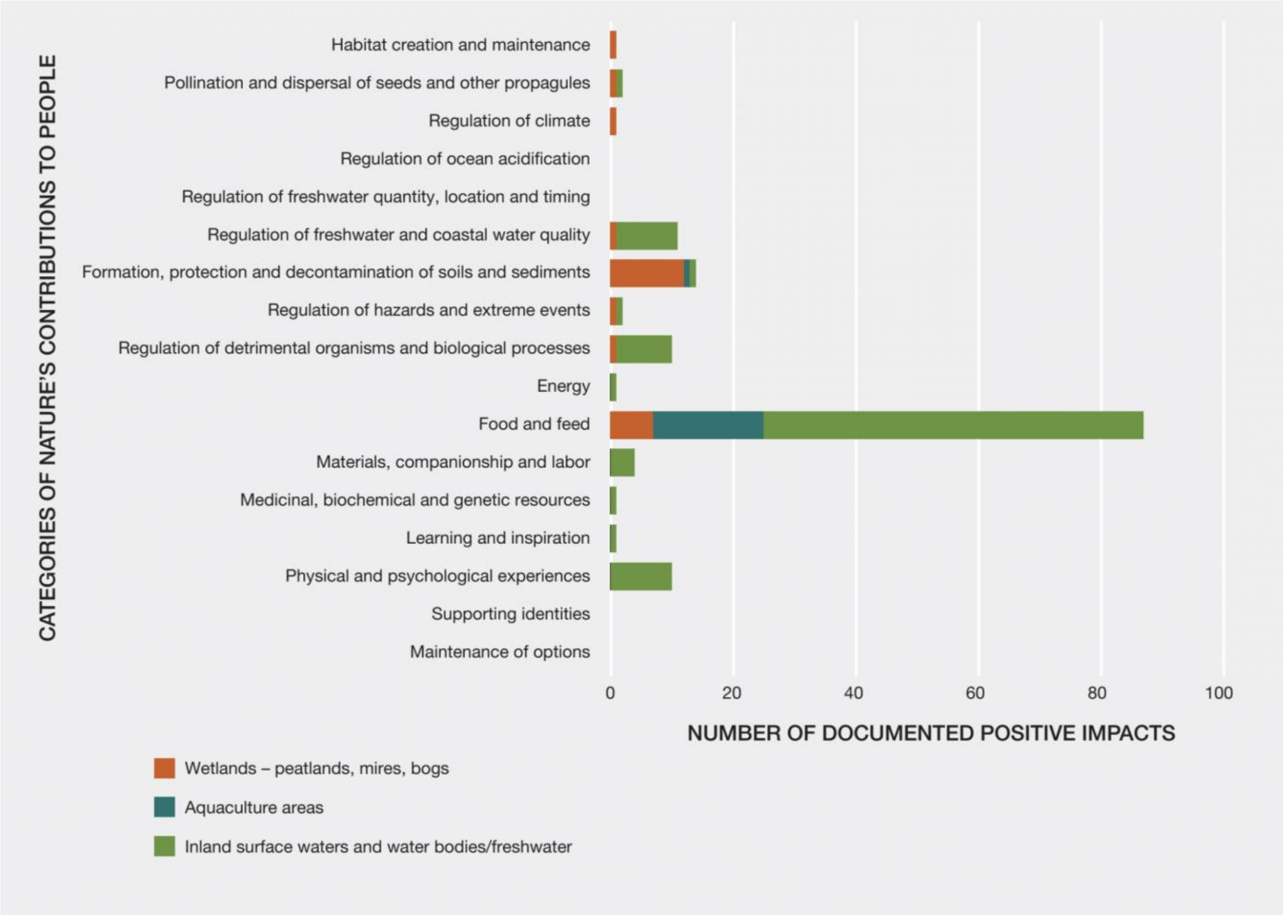


**Figure 4.33.** Documented positive impacts (x axis) of invasive alien species on categories of nature's contributions to people (y axis) in the inland waters realm. There are 145 documented positive impacts across all categories of nature's contributions to people in the inland waters realm. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

**Invasive alien taxa most often documented causing impacts on nature's contributions to people in the inland waters realm**

In aquaculture areas, as well as in inland surface waters/waterbodies, vertebrates are the invasive alien species causing the most impacts, both positive and negative, on nature's contributions to people (**Table 4.16**). Species causing positive impacts include *Hypophthalmichthys nobilis* (bighead carp), *Hypophthalmichthys molitrix* (silver carp), *Oreochromis niloticus* (Nile tilapia), *Cirrhinus mrigala* (mrigal carp), several species of catfish such as *Clarias gariepinus* (North African catfish), and also a reptile, *Crocodylus rhombifer* (Cuban crocodile). These species positively impact the provision of food and feed, and reflect the growing contribution of aquaculture to food security, especially in the Asia-Pacific region (De Silva, 2012); fish constitutes the main dietary protein in many countries of the region (e.g., in Cambodia; Nuov et al., 2005). However, many introduced fish species have also become associated with negative impacts on nature's contributions to people (**Box 4.10**). These include species originally introduced for aquaculture such as *Cyprinus carpio* (common carp), *Oreochromis mossambicus* (Mozambique tilapia), *Oreochromis niloticus*, *Clarias gariepinus*, *Hypophthalmichthys nobili*, *Hypophthalmichthys molitrix*; species originally introduced for aquatic weed control such as *Ctenopharyngodon idella* (grass carp); *Gambusia affinis* (western mosquitofish) introduced to control malaria by feeding on mosquito larvae; and *Poecilia reticulata* (guppy), an ornamental species introduced for the aquarium trade. These species are linked to negative impacts on native fish (an impact on nature; **section 4.3.2**) via competition, predation, hybridization, and physical and chemical alteration of habitat (Ciruna et al., 2004), which, in turn, negatively affect the category food and feed. For example, in the River Ganga, India, between 2004 and 2009, fish catch showed a 72 per cent decline of native fish accompanied by a 237 per cent increase in introduced species (especially *Cyprinus carpio*, *Clarias gariepinus*, and the two species of tilapia (A. K. Singh & Lakra, 2011).

In inland surface waters/waterbodies, the other dominant taxonomic group associated with negative impacts on nature's contributions to people are invertebrates, e.g., *Dreissena polymorpha* (zebra mussel), *Corbicula fluminea* (Asian clam), and *Procambarus clarkii* (red swamp crayfish). Of these, *Dreissena polymorpha* and *Procambarus clarkii* are each responsible for a number of negative impacts on nature's contributions to people. The former affects food and feed, regulation of freshwater and coastal water quality, energy, provision of materials and companionship and labour (Colautti et al., 2006; Strayer, 2009); the latter affects food and feed, habitat creation and maintenance, supporting identities, and learning and inspiration, leading to its evaluation as a high-risk species (Souty-Grosset et al., 2016). Despite its multiple negative impacts, *Procambarus clarkii* also causes positive impacts (on food and feed, and harvested commercially), and live individuals are still bought and sold for the aquarium trade (Souty-Grosset et al., 2016). Other examples of positive impacts by invertebrates are on the categories food and feed by *Pontastachus leptodactylus* (Danube crayfish) (Martinez-Cillero et al., 2019), regulation of detrimental organisms and biological processes by *Gammarus pulex* (common freshwater amphipod) that feeds on mosquito larvae (Dalal et al., 2020), and regulation of freshwater and coastal water quality by *Dreissena rostriformis bugensis* (quagga mussel), which increases water clarity (Verstijnen, 2019).

In wetlands, plants are the invasive alien species causing the most impacts, both negative and positive, on nature's contributions to people, with the exception of two vertebrate species. Negative impacts of plants are largely on the formation, protection and decontamination of soils and sediments. For instance, species such as *Reynoutria japonica* (Japanese knotweed) and *Heracleum pubescens* (Sosnowskyi's hogweed), affect soil food webs by negatively altering nematode communities (Čerevková et al., 2019; Renčo et al., 2019), and *Echinochloa pyramidalis* (limpopo grass) negatively impact habitat creation and maintenance in Mexico (López Rosas et al., 2005). Positive impacts of plants in wetlands include regulation of hazards and extreme events, and regulation of freshwater and coastal water quality. For example, *Phragmites australis* (common reed) in North America can buffer wetlands against the effects of sea level rise, and removes nutrients from agriculture runoff (Kettenring et al., 2012). The vertebrates among the top 10 invasive alien species in wetlands are *Rusa timorensis* (Sunda sambar deer), which has negative impacts on the regulation of freshwater quantity, location and timing due to grazing on vegetation that helps regulate water flows (Pallewatta et al., 2003); and *Bubalus bubalis* (Asian water buffalo), which causes positive impacts on food and feed, according to Indigenous Peoples and local communities in Australia (e.g., Albrecht et al., 2009; C. J. Robinson et al., 2005).

**Table 4.16.** Main invasive alien species impacting nature's contributions to people in the inland waters realm

The top 10 (by number of documented impacts) invasive alien species causing negative and positive impacts on nature's contributions to people in the inland waters realm by the affected units of analysis. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

Plants: Invertebrate: Vertebrate:

| Unit of analysis | Invasive alien species with negative impacts on nature's contributions to people | | | Invasive alien species with positive impacts on nature's contributions to people | | |
|---|---|---|---|---|---|---|
| | **Taxon** | **Species** | **Documented impacts** | **Taxon** | **Species** | **Documented impacts** |
| Aquaculture areas | | *Azolla filiculoides* (water fern) | 3 | | *Azolla filiculoides* (water fern) | *1* |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | *Cyprinus carpio* (common carp) | 10 | | *Seaweed Cottony II* | *1* |
| | | *Oreochromis mossambicus* (Mozambique tilapia) | 9 | | *Hypophthalmichthys nobilis* (bighead carp) | *2* |
| | | *Clarias gariepinus* (African catfish) | 7 | | *Oreochromis niloticus* (Nile tilapia) | *2* |
| | | *Hypophthalmichthys molitrix* (silver carp) | 5 | | *Cirrhinus mrigala* (mrigal carp) | *1* |
| | | *Oreochromis niloticus* (Nile tilapia) | 5 | | *Clarias gariepinus* (North African catfish) | *1* |
| | | *Ctenopharyngodon Idella* (grass carp) | 4 | | *Clarias* spp. (catfish) | *1* |
| | | *Gambusia affinis* (western mosquitofish) | 3 | | *Crocodylus rhombifer* (Cuban crocodile) | *1* |
| | | *Hypophthalmichthys nobilis* (bighead carp) | 3 | | *Gibelion catla* (catla) | *1* |
| | | *Poecilia reticulata* (guppy) | 3 | | *Hypophthalmichthys molitrix* (silver carp) | *1* |
| Inland surface waters and water bodies/fresh water | | *Dreissena polymorpha* (zebra mussel) | 36 | | *Dreissena rostriformis bugensis* (quagga mussel) | *6* |
| | | *Corbicula fluminea* (Asian clam) | 9 | | *Dreissena polymorpha (zebra mussel)* | *3* |
| | | *Procambarus clarkii* (red swamp crayfish) | 9 | | *Procambarus clarkii* (red swamp crayfish) | *3* |
| | | *Alternanthera philoxeroides* (alligator weed) | 9 | | *Gammarus pulex* (common freshwater amphipod) | *2* |
| | | *Cyprinus carpio* (common carp) | 20 | | *Pontastacus leptodactylus* (Danube crayfish) | *2* |
| | | *Oreochromis niloticus* (Nile tilapia) | 15 | | *Pistia stratiotes* (water lettuce) | *4* |
| | | *Oreochromis mossambicus* (Mozambique tilapia) | 13 | | *Oreochromis niloticus* (Nile tilapia) | *5* |
| | | *Hypophthalmichthys molitrix* (silver carp) | 12 | | *Bubalus bubalis* (Asian water buffalo) | *4* |
| | | *Clarias gariepinus* (North African catfish) | 11 | | *Lates niloticus* (Nile perch) | *4* |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | *Ctenopharyngodon Idella* (grass carp) | 9 | | *Gambusia affinis* (western mosquitofish) | *3* |
| Wetlands – peatlands, mires, bogs | | *Echinochloa pyramidalis* (limpopo grass) | 6 | | *Trichocorixa verticalis* (water boatman) | *2* |
| | | *Reynoutria japonica* (Japanese knotweed) | 5 | | *Sporobolus pumilus* (saltmeadow cordgrass) | *8* |
| | | *Heracleum pubescens* (Sosnowskyi's hogweed) | 5 | | *Heracleum pubescens* (Sosnowskyi's hogweed) | *2* |
| | | *Frangula alnus* (alder buckthorn) | 4 | | *Phragmites australis* (common reed) | *2* |
| | | *Elymus athericus* (wildrye) | 3 | | *Cenchrus clandestinus* (Kikuyu grass) | *1* |
| | | *Phalaris arundinacea* (reed canary grass) | 3 | | *Elymus athericus* (wildrye) | *1* |
| | | *Phragmites australis* (common reed) | 3 | | *Reynoutria japonica* (Japanese knotweed) | *1* |
| | | *Sporobolus pumilus* (saltmeadow cordgrass) | 3 | | *Impatiens glandulifera* (Himalayan balsam) | *1* |
| | | *Lythrum salicaria* (purple loosestrife) | 2 | | *Typha domingensis* (southern cattail) | *1* |
| | | *Rusa timorensis* (Sunda sambar deer) | 4 | | *Bubalus bubalis* (Asian water buffalo) | *3* |

## 4.4.2.3. Patterns of negative and positive impacts of invasive alien species on nature's contributions to people in the marine realm

**Impacted units of analysis in the marine realm**

In the marine realm, as with the terrestrial and inland waters realms, negative impacts of invasive alien species outweigh positive impacts on nature's contributions to people (85 and 24 documented impacts, respectively). Documented impacts of invasive alien species on nature's contributions to people are predominantly from shelf ecosystems (about 70 per cent of negative and over 85 per cent of documented positive impacts). The remainder of invasive alien species impacts are documented from coastal areas; there are no documented impacts from other marine units of analysis. There are far fewer documented impacts of invasive alien species impacts on nature's contributions to people from marine compared with terrestrial and inland waters units of analysis, which might largely be due to a bias in research efforts.

**Impacted categories of nature's contributions to people in the marine realm**

Negative impacts on the provision of food and feed predominate in shelf ecosystems and constitute 85 per cent of all documented impacts (caused by 23 species; **Figure 4.34**). Negative impacts in coastal areas are distributed across all categories of nature's contributions to people, though food and feed accounts for a large proportion of documented impacts (approximately 45 per cent, caused by 4 species); other categories of negative impacts in coastal areas include regulation of freshwater and coastal water quality (25 per cent documented impacts; 3 species), maintenance of options (17 per cent of documented impacts, 4 species), and materials, companionship and labour (12 per cent of documented impacts, 2 species).

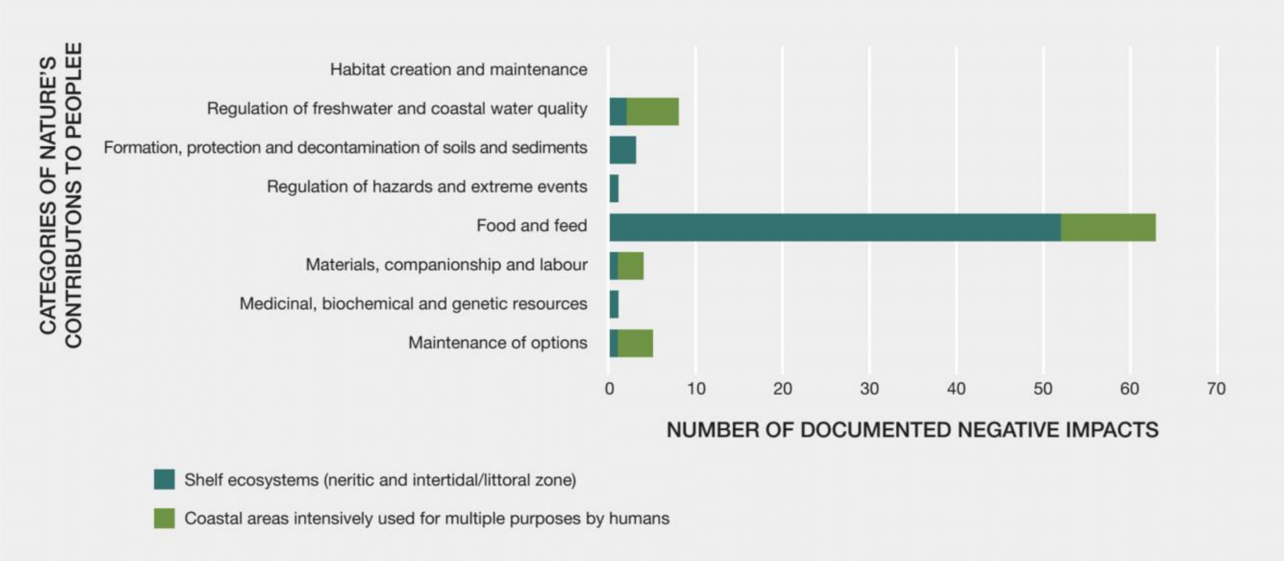


**Figure 4.34.** Documented negative impacts (x axis) of invasive alien species on categories of nature's contributions to people (y axis) across different marine units of analysis. There are 85 documented negative impacts across all categories of nature's contributions to people in the marine realm. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

Positive impacts (as with negative impacts) on the provision of food and feed predominate in both marine units of analysis (**Figure 4.35**). In the case of shelf ecosystems, food and feed constitutes 76 per cent of all documented impacts (caused by 16 species), with impacts on medicinal, biochemical and genetic resources accounting for an additional 14 per cent of documented impacts (caused by 1 species). Positive impacts of invasive alien species in coastal areas are all on the provision of food and feed (100 per cent of the three documented impacts, caused by 3 species).

This predominance of invasive alien species impacts (both negative and positive) on food and feed in the marine realm documented in the chapter impacts database matches findings from a recent European review of marine invasive alien species and their impacts on marine ecosystem services (Katsanevakis et al., 2014). Of all ecosystem services derived from marine ecosystems, Katsanevakis et al. (2014) found the highest number of documented invasive alien species with negative and positive impacts to be on food provisioning (fisheries, aquaculture); however, as suggested by the authors, this could reflect a study bias towards impacts on food, given its societal and economic relevance over other ecosystem services from marine ecosystems.

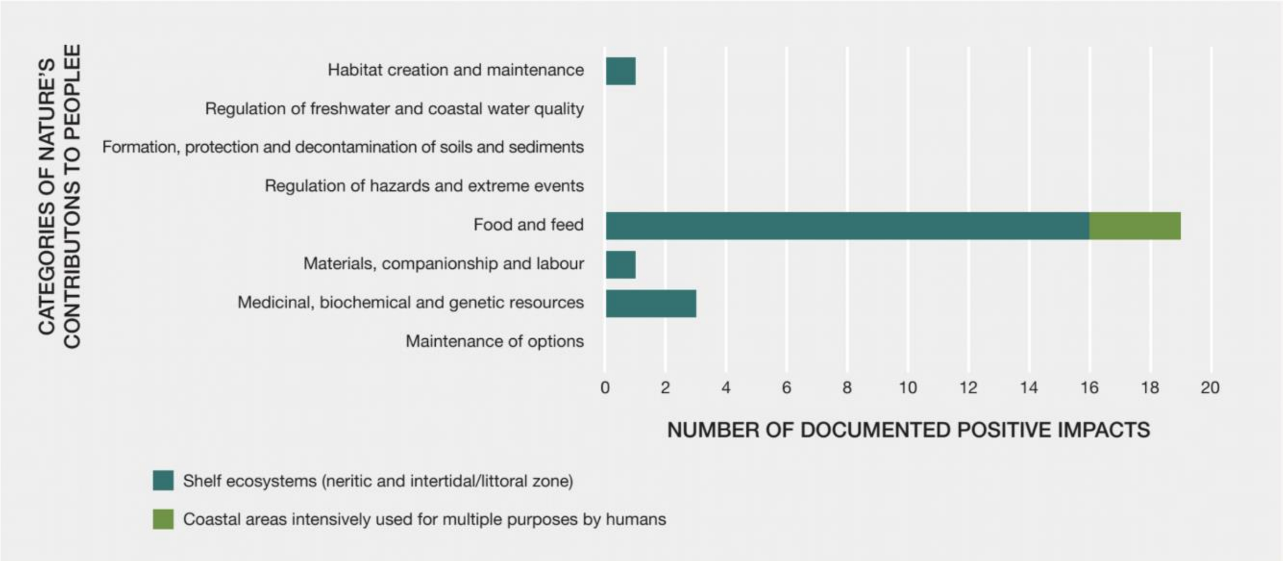


**Figure 4.35.** Documented positive impacts (x axis) of invasive alien species on categories of nature's contributions to people (y axis) across different marine units of analysis. There are 24 documented positive impacts across all categories of nature's contributions to people in the marine realm. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

**Invasive alien taxa most often documented causing impacts on nature's contributions to people in the marine realm**

In coastal areas, the most documented invasive alien species causing both negative and positive impacts on nature's contributions to people are all invertebrates (**Table 4.17**). The most documented negative impacts are on food and feed. Examples include impacts of *Carcinus maenas* (European green crab), which feeds on native oysters and crabs, and has decimated commercial shellfish beds in New England and Canada (Pimentel et al., 2000), and the generalist predators, *Asterias amurensis* (northern Pacific seastar) and *Ciona intestinalis* (sea vase), which affect mariculture and fisheries along the Korean coast (Seo & Lee, 2009). Another example is *Mytilopsis sallei* (Caribbean false mussel), which competitively displaces native clams and oysters that are locally important fishery resources in India (Kumar, 2019). In coastal areas, the documented positive impacts on nature's contributions to people caused by invasive alien species are all related to food and feed. All three species, *Magallana gigas* (Pacific oyster), *Penaeus vannamei* (whiteleg shrimp), and *Ruditapes philippinarum* (Japanese carpet shell), are commercially harvested (A. N. Cohen & Carlton, 1995; U.S. Congress, Office of Technology Assessment, 1993).

In shelf ecosystems, invasive alien invertebrates are responsible for the majority of both negative and positive impacts on nature's contributions to people, mostly on food and feed. For example, *Carcinus maenas* (European green crab), through predation, and *Styela clava* (Asian tunicate), through competition for space, have led to a reduction in populations of native species in fisheries (Colautti et al., 2006). Positive impacts of invertebrates are, likewise, associated with the provision of food and feed. For example, *Rapana venosa* (veined rapana whelk) in Turkey (Aydin et al., 2016) and *Penaeus aztecus* (northern brown shrimp) in the Nile Delta of Egypt (Sadek et al., 2018), are both harvested commercially. In addition to the documented invertebrate species, there are two plant species that feature in the list of top 10 invasive alien species: *Codium fragile* (dead man's fingers) and *Gracilaria vermiculophylla* (red alga). *Codium fragile* has been associated with losses to commercial eel, lobster, and oyster fisheries in Canada (Colautti et al., 2006). *Gracilaria vermiculophylla* is harvested for extraction of agar, which is used in the food industry (A. M. M. Sousa et al., 2010). There are also two vertebrate species on this top 10 list, *Pterois volitans* (red lionfish) and *Megalops atlanticus* (Atlantic tarpon). *Pterois volitans*, a predator, has caused population declines of native fish on which local fisherfolk depend (Miguez Ruiz, 2013). Analogous to the much better documented introductions through the Suez canal that is regarded as an extremely significant route of introduction for marine invasions (Galil et al., 2015), *Megalops atlanticus* is thought to have arrived in the eastern Pacific through the Panama Canal and was initially documented in the 1940s. It now extends on approximately 2600 km along the Pacific coastline of Central and South America (Castellanos-Galindo et al., 2019). Its impacts are perceived as positive by different communities along the Colombian coast as it is used as a resource for food, crafts, and also for game fishing in the tourism industry (Neira & Acero P, 2016).

**Table 4.17.** Main invasive alien species impacting nature's contributions to people in the marine realm

The top 10 (by number of documented impacts) invasive alien species causing negative and positive impacts on nature's contributions to people in the inland waters realm, by the affected units of analysis. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

Plants: Invertebrate: Vertebrate:

| Units of Analysis | Invasive alien species with negative impacts on nature's contributions to people | | | Invasive alien species with positive impacts on nature's contributions to people | | |
|---|---|---|---|---|---|---|
| | **Taxa** | **Species** | **Documented impacts** | **Taxa** | **Species** | **Documented impacts** |
| Coastal areas intensively used for multiple purposes by humans | | *Carcinus maenas* (European shore crab) | 6 | | *Magallana gigas* (Pacific oyster) | 1 |
| | | *Mytilopsis sallei* (Caribbean false mussel) | 4 | | *Penaeus vannamei* (whiteleg shrimp) | 1 |
| | | *Asterias amurensis* (northern Pacific seastar) | 3 | | *Ruditapes philippinarum* (Japanese carpet shell) | 1 |
| | | *Ciona intestinalis* (sea vase) | 2 | | | |
| | | *Teredo navalis* (naval shipworm) | 2 | | | |
| | | *Batillaria attramentaria* (Japanese false cerith) | 1 | | | |
| | | *Magallana gigas* (Pacific oyster) | 1 | | | |
| | | *Littorina littorea* (common periwinkle) | 1 | | | |
| | | *Lyrodus pedicellatus* (blacktip shipworm) | 1 | | | |
| | | *Mytella strigata* (Charru mussel) | 1 | | | |
| Shelf ecosystems (neritic and intertidal/littoral zone) | | *Carcinus maenas* (European shore crab) | 7 | | *Penaeus aztecus* (northern brown shrimp) | 4 |
| | | *Mytella strigata* (Charru mussel) | 5 | | *Laguncula pulchella* (predatory sea snail) | 3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | *Ficopomatus enigmaticus* (tubeworm) | 3 | | *Mytella strigata* (Charru mussel) | 2 |
| | | *Styela clava* (Asia tunicate) | 3 | | *Mytilus galloprovincialis* (Mediterranean mussel) | 2 |
| | | *Ascidiella aspersa* (European sea squirt) | 2 | | *Rapana venosa* (veined whelk) | 2 |
| | | *Ciona intestinalis* (sea vase) | 2 | | *Cercopagis pengoi* (fishhook waterflea) | 1 |
| | | *Ciona robusta* (tunicate) | 2 | | *Paralithodes camtschaticus* (red king crab) | 1 |
| | | *Tubastraea* spp. (sun corals) | 2 | | *Gracilaria vermiculophylla* (red alga) | 1 |
| | | *Codium fragile* (dead man's fingers) | 14 | | *Pterois volitans* (red lionfish) | 2 |
| | | *Pterois volitans* (red lionfish) | 2 | | *Megalops atlanticus* (Atlantic tarpon) | 1 |

### 4.4.3. Documented impacts on nature's contributions to people by region and taxonomic group

Many invasive alien species are causing negative impacts on nature's contributions to people in all regions, with documented impacts from more than 500 species in the Americas and Europe and Central Asia (538 and 531, respectively), followed by 314 species in the Asia-Pacific region and 136 in Africa (**Figure 4.36**). Across regions, some of these invasive alien species also have positive impacts on nature's contributions to people, and the percentage of species with documented positive impacts ranges from 22 per cent of species in Europe and Central Asia, 26 per cent in Africa, 32 per cent in the Americas, to 41 per cent in the Asia-Pacific region.

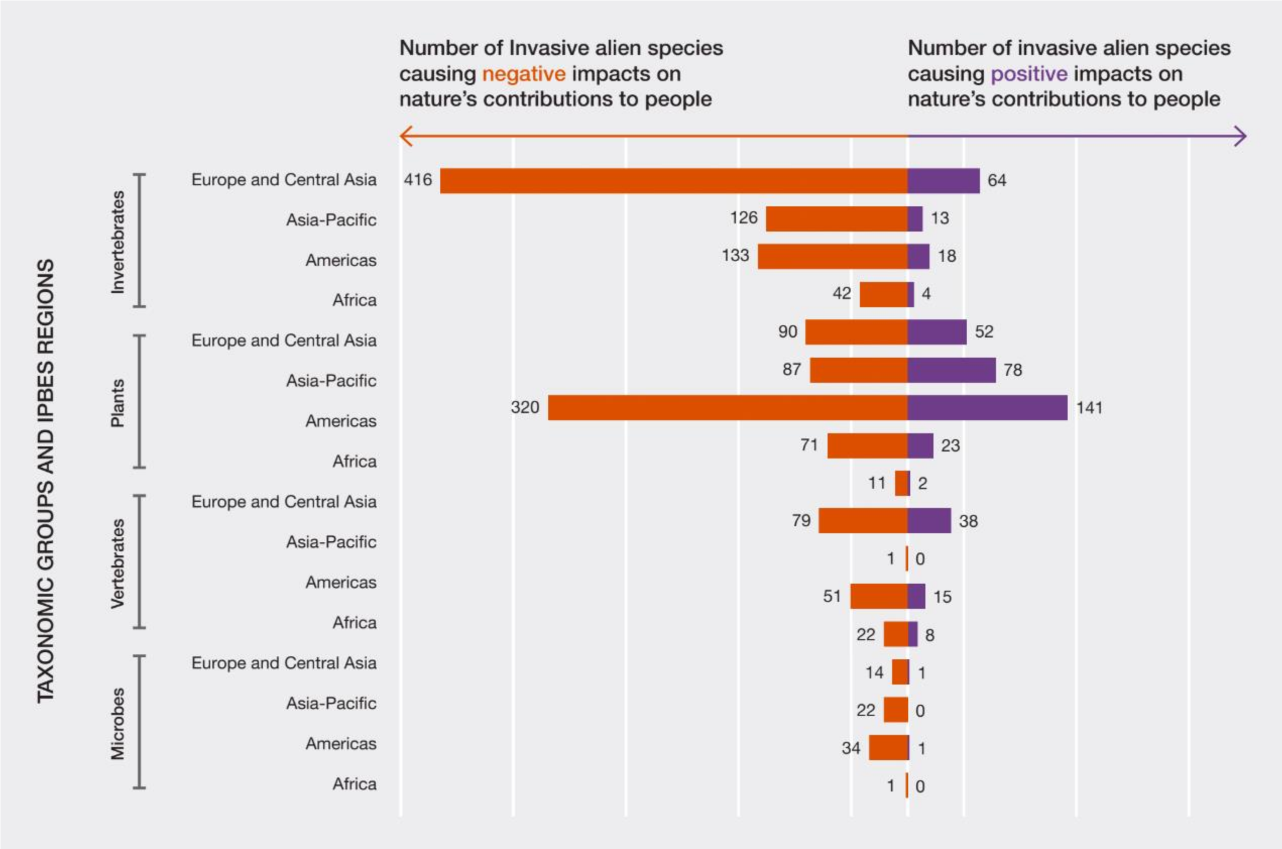


**Figure 4.36.** Number of invasive alien species with documented negative and positive impacts on nature's contributions to people (x axis) per region and taxonomic group (y axis). Positive and negative stacked bar charts do not imply that positive and negative impacts can be summed. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at [https://doi.org/10.5281/zenodo.5766069](https://doi.org/10.5281/zenodo.5766069)

**Most impacted categories of nature's contributions to people by region, and by taxon**

Across all regions, food provisioning is the most impacted category of nature's contributions to people, both negatively and positively. Negative impacts on provisioning of food are found in all regions and for all taxa (**Figure 4.37**). In Africa, most invasive alien species causing these impacts are plants (59 species), followed by invertebrates (36) and vertebrates (22), and with just one documented microbe species (Maize lethal necrosis disease). A similar pattern is observed for the Americas (131 plants, 76 invertebrates, 30 vertebrates, 22 microbes), whereas in the Asia-Pacific and Europe and Central Asia regions, invasive alien invertebrates are the largest taxonomic group causing impacts on food provisioning (81 and 217, respectively). The highest number of invasive alien vertebrates (74 species) causing impacts on food provisioning is found in the Asia-Pacific region.

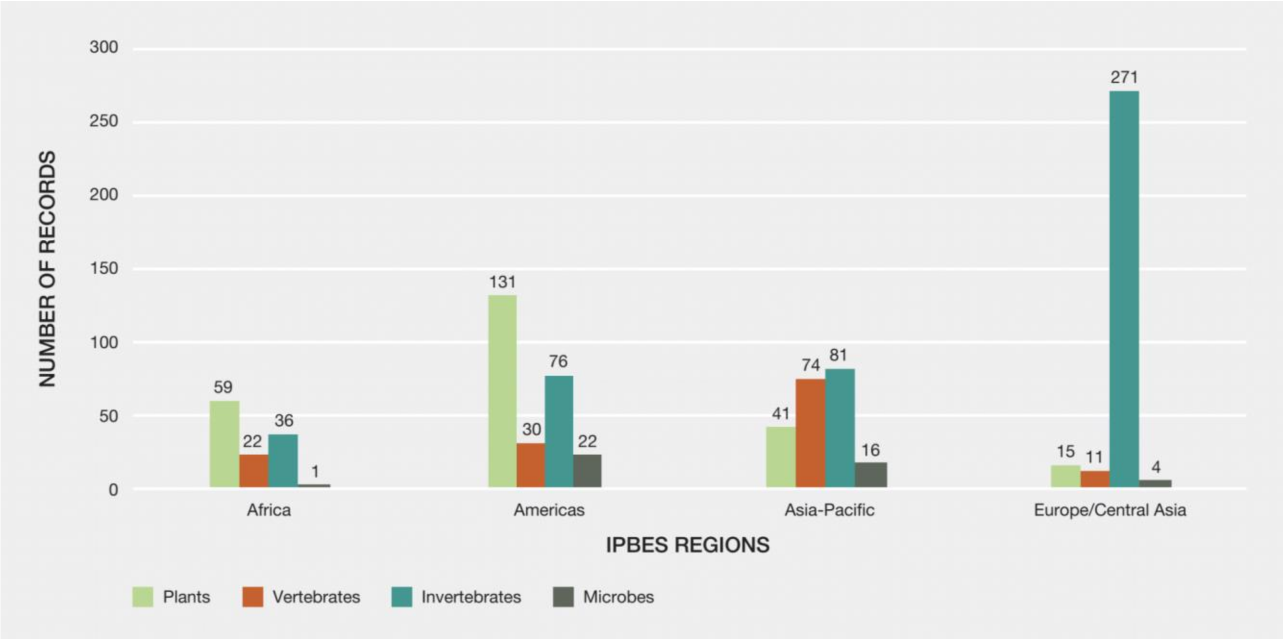


**Figure 4.37.** Number of documented impacts (y axis) of invasive alien species on food provisioning by region (x axis). The number of invasive alien species involved is indicated above each column. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

**Invasive alien taxa most often documented causing negative impacts by region**

There are more impacts caused by plants in Africa, the Americas and the Asia-Pacific regions than in Europe and Central Asia (**Figure 4.37**). In comparison to other regions, rangelands used for grazing livestock are less common in Europe and Central Asia than other regions of the world (Boone et al., 2018), where high numbers of invasive alien species impact food provisioning through overgrowing rangelands or by harming livestock with poisonous or injurious parts (**Box 4.9**). Impacts caused by invasive alien plants (as weeds in agricultural crops) are often not distinguished from impacts caused by native plants, especially when the impacts of the entire weed flora are assessed (Vilà et al., 2004), and are therefore likely to be underrepresented in the impact database developed through this chapter.[10] Pimentel et al. (2005) have estimated the impacts of invasive alien weeds in the United States by using the percentage of invasive alien agricultural weed species in the total weed flora to proportionate the crop losses caused by alien weeds. As a result, they estimated crop losses of US$24 billion annually based on the assumption of 12 per cent crop losses caused by weeds, of which 73 per cent were allocated to invasive alien weeds, corresponding to their share in the US agricultural weed flora.

A more comprehensive analysis of the impacts of plants across the four regions (**Table 4.18**) shows that in Europe and Central Asia, the highest number of different categories of nature's contributions to people is affected. In particular, impacts on soils by plants have been documented to be caused by 45 invasive alien species in this region, but there are also high numbers of plants impacting negatively on pollination (19) and biological processes (17). Across all regions, freshwater provision is the category of nature's contributions to people that is more consistently negatively impacted by invasive alien plants. The number of documented impacts on material provisions by invasive alien invertebrates is very high in Europe and Central Asia (173 invasive alien species) and is also high in the Americas (37) and Asia-Pacific (39) regions, but there is only one record in

[10] Data management report available at: https://doi.org/10.5281/zenodo.5766069

Africa. In Africa in particular, impacts on forestry have not been as well documented (both in the literature and in the impact database developed through this chapter)[11] as, for example, in North America (e.g., Aukema et al., 2011) or Europe and Central Asia. Europe also has a higher rate of documented new introductions of forest pests and diseases than other continents (Kenis et al., 2017; Santini et al., 2013).

Among immaterial nature's contributions to people, impacts on the maintenance of options by invasive alien plants have been documented in Africa (10) and Asia-Pacific (4), by vertebrates (34) and invertebrates (28) in the Americas, and for one microbe species in Asia-Pacific. Physical and psychological experiences have been impacted by 24 invasive alien plants in Europe and Central Asia, but also by invertebrates in the Americas, Asia-Pacific and Europe and Central Asia regions. There are eight plants with impacts on the "supporting identities" category, a further single record of one plant in this category for the Americas, of two invertebrates for Europe and Central Asia and of one microbe from the Asia-Pacific region.

**Table 4.18.** Number of invasive alien species with negative impacts on nature's contributions to people by taxonomic group and region

Acronyms used in the table: NCP – nature's contributions to people; Af – Africa; Am – Americas; AP – Asia-Pacific; ECA – Europe and Central Asia. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

| | **Plants** | | | | **Vertebrates** | | | | **Invertebrates** | | | | **Microbes** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NCP** | **Af** | **Am** | **AP** | **ECA** | **Af** | **Am** | **AP** | **ECA** | **Af** | **Am** | **AP** | **ECA** | **Af** | **Am** | **AP** | **ECA** |
| Habitat | 7 | 174 | 34 | 1 | 0 | 3 | 1 | 0 | 0 | 23 | 1 | 4 | 0 | 2 | 2 | 13 |
| Pollination | 1 | 46 | 0 | 19 | 0 | 1 | 0 | 0 | 0 | 5 | 5 | 2 | 0 | 0 | 0 | 0 |
| AirQuality | 0 | 2 | 8 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Climate | 0 | 4 | 0 | 6 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| OceanAcid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Freshwater | 17 | 21 | 14 | 12 | 0 | 1 | 1 | 0 | 0 | 2 | 0 | 6 | 0 | 0 | 0 | 0 |
| WaterQuality | 12 | 9 | 6 | 2 | 0 | 3 | 3 | 0 | 0 | 4 | 3 | 3 | 0 | 0 | 0 | 0 |
| Soils | 6 | 22 | 5 | 45 | 0 | 4 | 2 | 0 | 0 | 3 | 0 | 1 | 0 | 1 | 0 | 0 |
| Hazards | 1 | 25 | 7 | 3 | 0 | 2 | 1 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 |
| BiolProcess | 3 | 25 | 5 | 17 | 0 | 3 | 4 | 0 | 6 | 26 | 13 | 4 | 0 | 0 | 0 | 0 |
| Energy | 4 | 4 | 2 | 0 | 0 | 1 | 1 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Food | 59 | 131 | 41 | 15 | 22 | 30 | 74 | 11 | 36 | 76 | 81 | 217 | 1 | 22 | 16 | 4 |
| Materials | 8 | 15 | 13 | 0 | 0 | 5 | 4 | 0 | 1 | 37 | 39 | 173 | 0 | 10 | 4 | 0 |
| Medicinal | 4 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 5 | 0 | 0 | 0 | 1 |
| Learning | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Physical | 1 | 3 | 3 | 24 | 0 | 4 | 1 | 0 | 1 | 13 | 12 | 13 | 0 | 0 | 2 | 0 |
| Identities | 0 | 1 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 |
| Options | 10 | 0 | 4 | 0 | 0 | 34 | 0 | 0 | 0 | 28 | 2 | 0 | 0 | 0 | 1 | 0 |

[11] Data management report available at: https://doi.org/10.5281/zenodo.5766069

**Invasive alien taxa most often documented causing positive impacts by region**

Many invasive alien species (mostly plants) also provide benefits to people, which, in many cases, have been the reason for their initial or continued introduction (**Table 4.19**). Food provisioning can be improved by invasive alien plants and vertebrates in all regions. In the Americas, 66 invasive alien plants have documented uses as food or feed, but numbers are lower in other regions, with 21 documented impacts in Asia-Pacific, 13 in Africa and 7 in Europe and Central Asia. Invasive alien vertebrate species are mostly used for food and feed in the Asia-Pacific region (34 species), whereas in the Europe and Central Asia region, invertebrates (41 species) are the largest invasive alien species taxa group providing this category of nature's contributions to people. Further benefits from plants are documented for soils in Europe and Central Asia (38 species) and Asia-Pacific (26 species). Invasive alien plants are used across all regions for medicinal reasons and for energy generation. Benefits for climate, for example through carbon sequestration in soils, have been documented for invasive alien plants in Europe and Central Asia (13 species), in Africa (9 species), mainly for micro-climate impacts of shade and windbreaks and in Asia-Pacific (2 species). Invasive alien plants also provide material benefits (e.g., as timber), and 14 species have been documented for this category of nature's contributions to people both in Asia-Pacific and the Americas, with fewer species in the other regions. Most documented impacts of the use of invasive alien plants for energy are from Africa, where 12 woody invasive alien species are documented as being used as firewood.

**Table 4.19.** Number of invasive alien species with positive impacts on nature's contributions to people by taxonomic group and region

Acronyms used in the table: Af – Africa, Am – Americas, AP – Asia-Pacific, Ant – Antarctica, ECA – Europe and Central Asia, NCP – nature's contributions to people. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

| | Plant | | | | Vertebrates | | | | Invertebrates | | | | Microbes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NCP** | **Af** | **Am** | **AP** | **ECA** | **Af** | **Am** | **AP** | **ECA** | **Af** | **Am** | **AP** | **EC A** | **Af** | **Am** | **AP** | **EC A** |
| Habitat | 0 | 21 | 6 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Pollination | 0 | 5 | 0 | 11 | 0 | 1 | 1 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 |
| AirQuality | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Climate | 9 | 0 | 2 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| OceanAcid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Freshwater | 0 | 18 | 3 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WaterQualit y | 0 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| Soils | 0 | 11 | 26 | 38 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hazards | 0 | 3 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BiolProcess | 2 | 8 | 1 | 10 | 0 | 3 | 2 | 0 | 0 | 5 | 2 | 6 | 0 | 0 | 0 | 0 |
| Energy | 12 | 5 | 6 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Food | 13 | 66 | 21 | 7 | 5 | 11 | 34 | 2 | 3 | 10 | 7 | 41 | 0 | 1 | 0 | 0 |
| Materials | 5 | 14 | 14 | 2 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 10 | 0 | 0 | 0 | 0 |
| Medicinal | 6 | 42 | 33 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 |
| Learning | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| Physical | 0 | 0 | 3 | 6 | 5 | 1 | 1 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 |
| Identities | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Options | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## 4.5. Impacts of invasive alien species on good quality of life

### 4.5.1. General patterns

Many of all documented impacts of invasive alien species are known to directly or indirectly affect good quality of life (15.7 per cent, 3,783 impacts), ranging from impacts on people's material and immaterial assets (e.g., food, housing), health (**section 4.5.1.3**), safety, relationships with people and nature, and maintaining opportunities for the future (i.e., the different constituents of good quality of life; **section 4.1.1**, **Box 4.3**). Globally, 1,032 invasive alien species have documented impacts on good quality of life, with 900 invasive alien species causing negative impacts and 236 causing positive impacts. Among those, 104 invasive alien species cause both positive and negative impacts, with both benefits and costs for good quality of life. These particular species can pose challenges for decision makers because they are differently perceived by different stakeholders (**Chapter 5**, **section 5.6.1.2**; **Figure 4.38**). The 796 invasive alien species causing only negative impacts is reflective of the higher number of negative impacts documented for good quality of life, which is spread across all taxa, regions and units of analysis (**sections 4.5.2** and **4.5.3**).

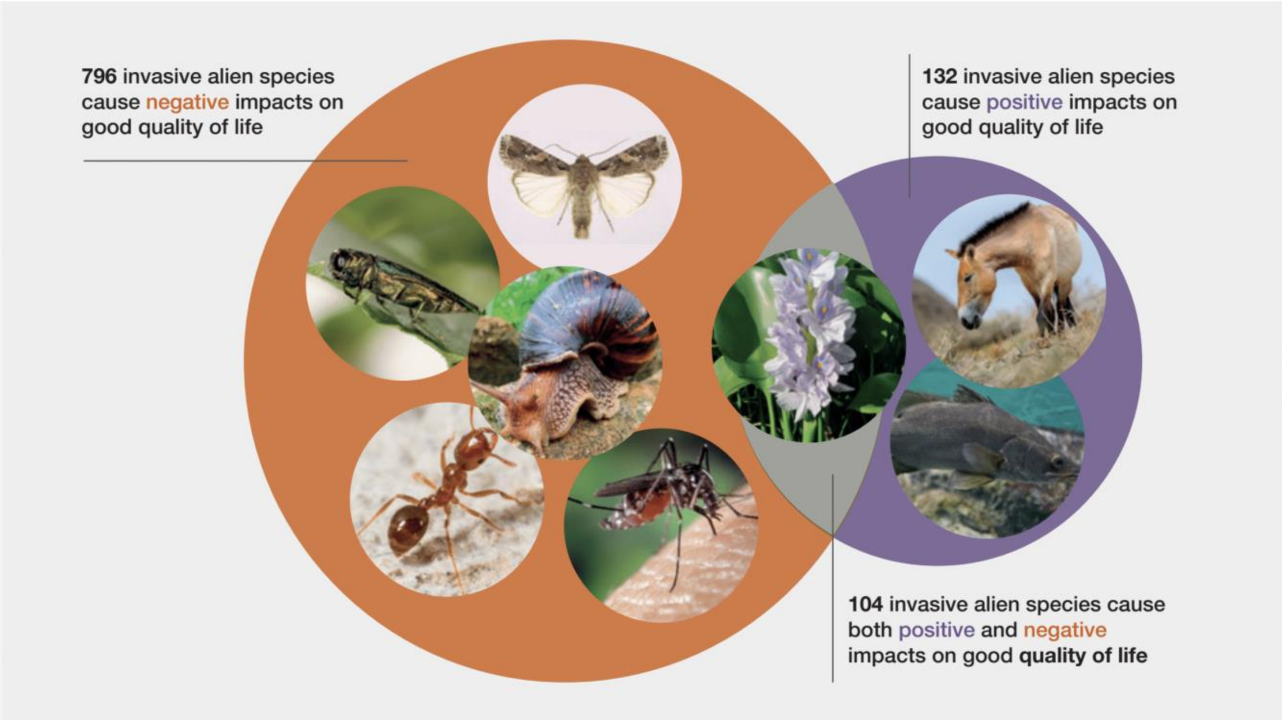


**Figure 4.38.** Invasive alien species mostly cause negative impacts on good quality of life. Number of invasive alien species causing only negative impacts on good quality of life (left), negative and positive impacts (centre) and positive impacts only (right). Please note that the size of the segments is not proportional to the numbers. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069. Photo credits: Stephen Ausmus, USDA Agricultural Research Service – Public domain (Emerald ash borer) / Marián Polák, WM Commons – CC BY-SA 4.0 (wild horse) / Daiju Azuma, WM Commons – CC BY-SA 4.0 (Nile perch) / Bharat Shrestha – CC BY 4.0 (water hyacinth) / Canadian Biodiversity Information Facility, WM Commons – Public domain (fall armyworm) / Sonel, pixabay – CC BY 4.0 (Giant African land snail) / James Gathany, CDC, WM Commons – Public domain (Asian tiger mosquitos) / elharo, Adobe Stock – Copyright (red imported fire ant).

**Most impacted constituents of good quality of life**

Globally, the most impacted constituents of good quality of life, both in terms of negative and positive impacts, are material and immaterial assets (**Table 4.20**), which account for almost two-thirds (60.4 per cent, 2286 impacts) of the documented impacts. The number of negative documented impacts is approximately six times higher than that of the positive impacts, which is likely due to the fact that this constituent is directly related to livelihood of people, and is therefore documented more frequently. Positive impacts on material and immaterial assets have often resulted from the initial introduction of the invasive alien species for a specific purpose, for example food crops or plants delivering materials for fuel, which help people to improve their quality of life. However, if these species spread into natural areas, they can lead to negative impacts such as reduction in food gathered from nature, or yields from forestry and fisheries, therefore contributing to economic hardship, poverty and food insecurity for the same people or different stakeholders. Alternatively, invasive alien plants may cause initial negative impacts on material and immaterial assets, then people can adapt and find some benefits from the species. For example, after the intentional introduction of the tree *Prosopis juliflora* (mesquite) as forage for livestock and habitat stabilization, which led to widespread loss of native grassland, people have adapted to novel *Prosopis*-based livelihoods, especially by making charcoal and harvesting the wood for sale (**Box 4.9**); this livelihood diversification and increased financial capital has enabled communities to cope better with environmental shocks (Sato, 2013; Walter & Armstrong, 2014). Parts of the tree have traditionally been used for medicinal purposes, and people are adapting it for medicinal use in its introduced habitats as well (Damasceno et al., 2017; Duenn et al., 2017). It is important to note that some communities do not voluntarily adapt to a species and its positive impact; they may not have had a choice, and their preferred option may still be the native species. Furthermore, adaptation does not necessarily increase the resilience (**Glossary**) of socioecological systems (**section 4.6**). Although some invasive alien species may be considered "useful" by particular groups of stakeholders, their presence is likely to have negative consequences for others, creating potential for conflict. In the Eastern Cape of South Africa, for example, *Opuntia ficus-indica* (prickly pear) provides a source of food and income for some local communities, but negatively impacts subsistence farmers by reducing the carrying capacity of land for livestock. The capacity to derive benefits such as food or energy from *Opuntia* spp. can even vary within local communities, whereby some women's groups are able to produce biogas and *Opuntia* jam and fruit juice, while others in the community do not have this capacity (IPBES, 2022).

Invasive alien species also greatly affect human health, which accounts for nearly one quarter of the impacts on good quality of life (22.2 per cent, 839 documented impacts), with 87 per cent of those impacts being negative (**Table 4.20**, **Boxes 4.15** and **4.16**). Together, the documented impacts on social, spiritual and cultural relations, safety and freedom of choice and action represent 14.2 per cent (536 documented impacts) of all the impacts on good quality of life and are also mainly negative impacts (77.8 per cent, **Table 4.20**). Many invasive alien species reduce access to grazing areas and water sources, resulting in food insecurity and possible conflicts among pastoralist communities (**Box 4.9**). The cultivation of *Acacia mangium* (brown salwood) has been documented to threaten the cultural and material continuity of the Wapichana and Macuxi in Brazil (Souza et al., 2018). Invasive alien plants that form dense monocultures in semi-arid ecosystems, such as *Cenchrus ciliaris* (buffel grass), can physically block access to culturally important places, reducing socially valuable native species, and ultimately changing the opportunities for cultural knowledge transmission and well-being of future generations (Read et al., 2020). Physical damage to ecosystems (e.g., changing water quality), can have a negative impact on people for whom water sources are sacred and central to their culture and well-being (**Box 4.14**). Human safety is directly at risk from, for instance, falling branches due to dead or dying trees as a result of invasive alien species outbreaks, and indirectly impacted from, for instance, increased intensity of fires caused by more flammable invasive grasses (**Chapter 1**, **Box 1.4**). Impacts of invasive animals on personal safety are however more concerning, with, for instance, *Sturnus vulgaris* (common starling) nests near airports that put human lives and aviation equipment at risk regularly (Linz et al., 2007). Larger invasive animals such as *Sus scrofa* (feral pig) or *Camelus dromedarius* (dromedary camel) are also known to directly scare or attack people or cause collisions and road accidents (Koichi et al., 2012; Vaarzon-Morel, 2010). Invasive alien plants indirectly reduce people's safety as larger shrubs and trees have been documented to harbour wildlife that encroach on human settlements, increasing human-wildlife conflicts and impacting the safety of people; this has been especially documented by Indigenous Peoples and local communities (Puri, 2015; Sundaram et al., 2012).

**Table 4.20.** Number of negative and positive impacts on constituents of good quality of life caused by invasive alien species

The number of impacts documented for each constituent of good quality of life. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

| Constituent of good quality of life | Negative impacts | Positive impacts |
|---|---|---|
| Material and immaterial assets | 2005 | 281 |
| Health | 728 | 111 |
| Social, spiritual and cultural relations | 240 | 97 |
| Safety | 82 | 18 |
| Freedom of choice and action | 95 | 4 |
| Unknown | 58 | 64 |
| Grand Total (%) | 3208 (85%) | 575 (15%) |

**Ratio of positive and negative impacts on good quality of life**

More than 6 out of 7 (3208 impacts, 85 per cent) documented impacts of invasive alien species on good quality of life are negative, and far fewer (575 impacts, 15 per cent) are positive for good quality of life. The ratio of negative to positive impacts on good quality of life caused by invasive alien species, is approximately 6 to 1. Other reviews of impacts of invasive alien species on human livelihoods have found higher proportions of beneficial impacts being documented. For instance, R. T. Shackleton, Shackleton, et al. (2019) have reviewed 51 case studies, in which 86 per cent of case studies documented detrimental impacts on human livelihoods and 79 per cent documented positive impacts on livelihoods. Similarly, in a review of 70 case studies, P. L. Howard (2019) has found that 90 percent of the case studies examined show evidence of harmful impacts on various ecosystem services and livelihood measures, while approximately 65 percent of the case studies document at least some positive effects. These reviews generally include groups of people with high dependence on nature for livelihoods, including, but not limited to, Indigenous Peoples and local communities. With a close proximity and reliance on natural resources, such communities may be the first to experience impacts of invasive alien species, but they also may be able to adapt and derive benefits when livelihoods are at stake (P. L. Howard, 2019; **section 4.6**). Therefore, the comparison of costs and benefits of invasive alien species will vary depending on the social-economic context, and some do not consider benefits as wholly "positive", and instead form part of trade-offs or more complex perspectives (IPBES, 2022).

**Gender-differentiated impacts**

Indigenous Peoples and local communities, ethnic minorities, migrants, poor rural and urban communities are disproportionately impacted by invasive alien vector-borne diseases (**section 4.5.1.4**; Bardosh et al., 2017; Molyneux et al., 2011). Gender bias is documented in some studies of invasive alien species impact upon people's livelihoods. Gender-differential impacts occur when invasive alien species limit or provide a resource which is gender-preferentially utilized. Male-dominated artisanal fisheries in Lake Victoria, dependent on tilapia for livelihood and food security, has declined due to the invasion of *Pontederia crassipes* (water hyacinth). The impact of

*Pontederia crassipes* on the catchability was more important in the Kenyan section of Lake Victoria, where the tilapia population was reduced by 45 per cent (Kateregga & Sterner, 2009; Ongore et al., 2018). In the gender-based division of labour among Rabari pastoralists in northwest India, men are responsible for the herd's health, access to water sources, fodder, camping sites, and face the negative impacts of *Prosopis juliflora* (mesquite; Duenn et al., 2017). Similarly, women among the buffer zone community forest users of Chitwan National Park, Nepal, who are responsible for collecting grasses and fodder, reported that the invasive *Mikania micrantha* (bitter vine) makes collection of forest resources increasingly difficult (Rai & Scarborough, 2015; Sullivan et al., 2017). The invasion of the forest reserve in Chamarajanagar, Karnataka, India, by *Lantana camara* (lantana) has been perceived by the neighbouring Lingayat women as contributing to the decline of a native palm. Palm-leaf broom making is one of the few income earning options available to them in the village (Kent & Dorward, 2015).

Some invasive alien species, such as *Acacia mearnsii* (black wattle), are widely used by Indigenous Peoples and local communities. In the Eastern Cape, South Africa, rural communities made widespread consumptive use, with 97 per cent of households in rural communities collecting wattle for fuelwood and building or fencing. While 53 per cent of the community members (men & women) prefer high densities of the shrub, 10 per cent fear criminals hiding in the *Acacia mearnsii* forests (C. M. Shackleton et al., 2007).

Some invasive alien species provide food, fuel and income to women belonging to Indigenous Peoples and local communities, and help bring them into the mainstream economic activity. In most developing countries, the majority of marginalized coastal villagers impacted by invasive alien seaweed (e.g., *Kappaphycus*, *Eucheuma*) farming and small-scale processing are women. Economic gains from seaweed farming contributed to positive changes in the quality of life, in food, shelter, clothing, health care and social acceptance (Krishnan & Kumar, 2010; Msuya & Hurtado, 2017; Rameshkumar & Rajaram, 2019). In South Sulawesi, Indonesia, women documented seaweed farming as generating 50 per cent or more of their household income (Larson et al., 2021; Rimmer et al., 2021). In Kibuyuni, on the south coast of Kenya, women comprise 75 per cent of seaweed farmers. The income earned has empowered them to participate in societal issues and family decision-making processes (Mirera et al., 2020).

There is very little systematic research on gender differences in impacts of invasive alien species beyond anecdotal evidence of direct impacts (for further examples see IPBES, 2022). The available data suggest that invasive alien species may, on occasion, cause impacts that are gender-biased, and gender-differentiated positive impacts may, in some cases, outweigh negative ones.

**Invasive alien species most often documented causing negative impacts on good quality of life**

The impact database developed through this chapter shows that there is a subset of invasive alien species that cause a disproportionate negative impact on good quality of life.[12] One-quarter of all negative impacts on good quality of life are caused by only 3 per cent (29 species) of all invasive alien species (**Table 4.21**).

Six of the top 10 invasive alien species with the highest frequency of negative impacts on good quality of life (**Table 4.21**) are the same as those in the top 10 list of those invasive alien species that cause negative impacts on nature's contributions to people in the food and feed category (**section 4.4.1**; **Table 4.14**), which demonstrates how invasive alien species can harm good quality of life by negatively impacting the quality and availability of services and contributions from nature. *Spodoptera frugiperda* (fall armyworm; **Box 4.18**), *Bactrocera dorsalis* (Oriental fruit-fly), *Phenacoccus manihoti* (cassava mealybug), and *Lissachatina fulica* (giant African land snail) are serious pests of crops that affect the nature's contributions to people food and feed category, which

[12] Data management report available at: https://doi.org/10.5281/zenodo.5766069

then flows onto to affect people's access to material assets and support their livelihoods. Impacts of invasive alien species may also flow to other foundations underpinning good quality of life such as human health, for example, not only does *Lissachatina fulica* cause damage to crops, with Indigenous Peoples and local communities reporting that farmers have had to abandon their farms in Antigua and Barbuda after this damage, but they also affect human health by carrying a parasite that causes meningitis (IPBES, 2020).

In addition to serious crop pests, the top 10 most frequently documented invasive alien species with negative impacts on good quality of life (**Table 4.21**) include two microbial pathogens that cause dieback of plants, in this case important tree species such as *Fraxinus* spp. (ash) and *Quercus* spp. (oak), which are valued worldwide for amenity, climate regulation, and cultural traditions (Poland et al., 2017). As a group, microbes causing tree dieback impact multiple constituents of good quality of life. For example, *Phytophthora cinnamoni* (Phytophthora dieback), *Phytophthora agathidicida* (kauri dieback), and *Austropuccinia psidii* (myrtle rust), which causes dieback of myrtaceous species such as the cultural keystone tree *Agathis australis* (kauri) in New Zealand, and *Eucalyptus* and *Melaleuca* (paperbarks) globally. *Eucalyptus* and *Melaleuca* support multiple livelihoods and major industries: where *Austropuccinia psidii* has caused a decline in tree health and subsequent yield losses of up to 70 per cent in *Melaleuca* oil plantations, fungicides needed to be applied, which limited the freedom of choice and action for growers, as they no longer had the option to be certified as organic producers (Carnegie & Pegg, 2018). Kauri trees are a key part of ancestral stories and spirituality for Māori in New Zealand (referred to as a taonga species), and the observed dieback of mature kauri trees in New Zealand has caused widespread concern about the potential impacts on spiritual and cultural relationships, although more collaboration is needed between Māori knowledge and science knowledge systems to document how impacts on nature are also affecting good quality of life (Kauri Protection Governance Group, 2022).

**Table 4.21.** Main invasive alien species causing negative impacts on good quality of life

The top 10 (by number of documented impacts) invasive alien species causing negative impacts on good quality of life, organized by highest frequency of documented impacts. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at [https://doi.org/10.5281/zenodo.5766069](https://doi.org/10.5281/zenodo.5766069)

Plants: Invertebrate:

Vertebrate: Microorganisms:

| **Invasive alien species** | **Taxa** | **Frequency of negative impacts documented for constituents of good quality of life** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Assets** | **Health** | **Relations** | **Safety** | **Freedom** | **Total reports** |
| *Lissachatina fulica* (giant African land snail) | | 42 | 40 | 0 | 0 | 0 | 82 |
| Dengue virus | | 30 | 38 | 0 | 0 | 8 | 76 |
| *Solenopsis invicta* (red imported fire ant) | | 32 | 39 | 0 | 3 | 0 | 74 |
| *Pontederia crassipes* (water hyacinth) | | 0 | 27 | 6 | 0 | 18 | 51 |
| *Spodoptera frugiperda* (fall armyworm) | | 46 | 0 | 0 | 0 | 0 | 46 |
| *Bactrocera dorsalis* (Oriental fruit fly) | | 40 | 0 | 0 | 0 | 0 | 40 |
| *Phenacoccus manihoti* (cassava mealybug) | | 35 | 0 | 0 | 0 | 0 | 35 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Phytophthora ramorum* (sudden oak death) | | 32 | 0 | 0 | 0 | 0 | 32 |
| *Hymenoscyphus fraxineus* (ash dieback) | | 26 | 0 | 0 | 0 | 0 | 26 |
| *Cyprinus carpio* (common carp) | | 24 | 0 | 0 | 0 | 0 | 24 |

**Table 4.22** presents the top 10 invasive alien species causing negative impacts on more than one constituent of good quality of life, with a different ranking to the one based solely on the highest number of documented impacts for any category (**Table 4.21**). It represents a broader range of impacts beyond material and immaterial assets. Some species appear on both tables: for example, Dengue virus causes damage to material and immaterial assets and health as well as freedom of choice and action and has a high number of reports across these categories. Other invasive viruses and human disease-causing microbes may well rank highly for impacts on good quality of life but have not been as well incorporated in the impact database developed through this chapter.[13] Some invasive alien species, whilst not documented as frequently as those in **Table 4.22**, were documented on a broader range of constituents of good quality of life, including *Dreissena polymorpha* (zebra mussel), *Lymantria dispar* (gypsy moth), *Ailanthus altissima* (tree-of-heaven), and *Agrilus planipennis* (emerald ash borer) (**Box 4.14**). *Sus scrofa* (feral pig) affects human social and cultural relations and safety, and is probably representative of other invasive hard-hooved larger herbivores, whereby they damage important cultural sites and species, and can attack people or cause road accidents (C. J. Robinson & Wallington, 2012; Vaarzon-Morel, 2010).

**Table 4.22.** Main invasive alien species causing negative impacts on more than one constituent of good quality of life

The top 10 (by number of documented impacts) invasive alien species causing negative impacts on more than one constituent of good quality of life, representing invasive alien species with the broadest impacts on good quality of life. Dark shading represents species affecting 3 constituents, light shading those affecting 2 constituents. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

Plants: Invertebrate:

Vertebrate: Microorganisms:

| Invasive alien species | Taxa | Constituents of good quality of life | | | | | |
|---|---|---|---|---|---|---|---|
| | | Assets | Health | Relations | Safety | Freedom | Number of constituents affected |
| Dengue virus | | Yes | Yes | | | Yes | 3 |
| *Solenopsis invicta* (red imported fire ant) | | Yes | Yes | | Yes | | 3 |
| *Pontederia crassipes* (water hyacinth) | | | Yes | Yes | | Yes | 3 |
| *Dreissena polymorpha* (zebra mussel) | | | Yes | Yes | | Yes | 3 |
| *Agrilus planipennis* (emerald ash borer) | | | | Yes | Yes | Yes | 3 |
| *Lissachatina fulica* (giant African land snail) | | Yes | Yes | | | | 2 |

[13] Data management report available at: https://doi.org/10.5281/zenodo.5766069

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Wasmannia auropunctata* (little fire ant) | | | Yes | Yes | | | 2 |
| *Sus scrofa* (feral pig) | | | | Yes | Yes | | 2 |
| *Ailanthus altissima* (tree-of-heaven) | | | | Yes | Yes | Yes | 2 |
| *Lymantria dispar* (gypsy moth) | | | | Yes | | Yes | 2 |

**Box 4.14. Impacts of emerald ash borer on Kanienkehá:ka (Mohawk) and W8banaki (Abénakis) Nations lands and the interaction with proposed policy responses**

*Agrilus planipennis* (emerald ash borer) is an invasive beetle from Asia whose lifecycle is dependent on ash trees. This invasive alien species was first discovered near the Great Lakes region of North America in 2002 and has since spread widely, killing millions of ash trees in North America (Haack et al., 2002; Herms & McCullough, 2014). Many Indigenous nations have a special relationship to the ash tree, especially *Fraxinus nigra* (black ash – Maahlakws in Aln8ba8dwaw8gan (w8banaki language) and éhsa in Kanien'kéha (Mohawk language). Black ash is used in traditional arts such as basketry (Frey et al., 2019; Poland et al., 2017). In the past and still today, the loss of access to black ash due to land privatization, environmental pressures, and the emerald ash borer has had a significant impact on basket making (Blanchet et al., 2022). In turn this results in a loss of traditional knowledge and language about this important cultural practice.

More than handicraft, basketry represents a symbol of cultural resilience for many nations, like the Kanienkehá:ka (Mohawk) and W8banaki (Abénakis) (**Figure 4.39**). The practice survived despite all odds and the many obstacles that colonization and governmental restrictions have imposed over centuries. The art of basket making is embedded in Kanien'kehá:ka and W8banaki culture, identity, and spirituality. It has also been an important source of income for generations and continues today. According to the W8banakiak creation story, they come from black ash and their existence has always been interwoven. According to oral tradition, without the tree, W8banakiak (the -ak marks the plural) would not exist and if it would disappear, the Nation would as well. Furthermore, still today, many funeral urns are made of black ash. Thus, their identity "stems from the species", according to Martin Gill, Aln8ba from Odanak, (Blanchet et al., 2022), and black ash is what holds the community together.

In 2018, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the black ash tree as threatened (COSEWIC, 2018). This assessment prompted the Canadian government to consider listing the species under the federal *Species at Risk Act* (SARA). Listing the black ash in Canadian law would provide funding for recovery, but it would also impose restrictions such as a ban on selling ash baskets, and this would have devastating impacts on indigenous basketry, even though the practice of indigenous basketry is not causing the decline of black ash – the emerald ash borer is causing this decline. This approach also creates conflict between the Canadian view of conservation and Indigenous rights and relationship to the black ash. As an alternative approach, Indigenous Peoples have been actively researching and implementing measures to assure the protection and conservation of the black ash species, including monitoring, treatment, seed saving, and research collaborations (Poland et al., 2017; Reo et al., 2017) including W8banaki collaborations with University of Laval, Quebec. For example, sharing Indigenous and local knowledge, in this case about submerging black ash logs prior to harvest, has since been transferred to mainstream management as a suitable technique to reduce the survival of emerald ash borer (Poland et al., 2017).

Banning the sale of baskets would significantly impact the ability to practice basketry, especially considering the existing pressures on the practice. This would then be a direct negative impact on the autonomy, rights and cultural identity of the Indigenous Peoples who practice this tradition and is counter-productive to the principal of self-determination.

“This would be the beginning of the end for basketry, teachings must continue so that the practice can be transmitted to future generations. We can’t survive off love [and good faith] alone – we can’t be giving them [baskets] away or keeping them for ourselves” Daniel G. Nolett, Aln8ba from Odanak (Blanchet et al., 2022).

“They would be taking a part of me. I cannot begin to conceive my existence without my relationship to black ash” Suzie O’Bomsawin, Aln8baskwa from Odanak *(Blanchet et al., 2022).*

Women are likely to be particularly affected if there were a ban on the sale of baskets. For women, the sale of baskets is an incentive for not only their production and importance in household economies, but also for the intergenerational transmission of associated knowledge and skills. Long term impacts of this approach could see any entire generation lose access to basketry skills, and basketry practice and associated cultural identity would likely disappear.

**Figure 4.39.** Basketry, a symbol of cultural resilience for the Kanienkehá:ka (Mohawk) and W8banaki (Abénakis). Black Ash trees and the process of basketmaking using prepared strips of Black Ash wood (right) has special cultural significance for many First Nations in North Amercia. Baskets (centre and left) are more than handicrafts, as they are symbols of cultural identity and resilience, the practice supports knowledge transfer between generations and they are integral to local economies, especially for women. Emerald Ash Borer has killed millions of Black Ash trees and policies to protect the Black Ash, such as banning the sale of baskets, may further threaten the cultural, social and economic livelihoods of First Nations people. Photo credit: Musée des Abénakis – Copyright.

**Invasive alien species most often documented causing positive impacts on good quality of life**

In contrast to the top 10 invasive alien species causing negative impacts on good quality of life, which are mainly invertebrates and microbes, positive impacts on good quality of life are being derived primarily from invasive alien plants and vertebrates (**Table 4.23**). These invasive alien plants have been introduced to multiple countries to either provide land and/or water rehabilitation, ornamental or shade purposes (*Robinia pseudoacacia* (black locust), *Pontederia crassipes* (water hyacinth), *Ailanthus altissima* (tree-of-heaven)), or livelihood resources (*Proposis juliflora* (mesquite)), from which people in multiple countries derive benefits that improve their quality of life (**section 4.6**). However, all of these four species in particular have negative impacts on nature, nature’s contributions to people and good quality of life as well, with *Ailanthus altissima* also listed as one of the top 10 invasive alien species with negative impacts on more than one aspect of well-being. These four invasive alien plant species have been well-studied in the literature and thus, benefits to good quality of life are frequently documented alongside negative impacts.

Similarly, the three vertebrates in this top 10 listing of positive impacts also have negative impacts on nature, nature's contributions to people and good quality of life. *Cyprinus carpio* (common carp), *Oreochromis niloticus* (Nile tilapia), and *Oreochromis mossambicus* (Mozambique tilapia) are freshwater fish that have been introduced and adapted to as a food source and to support fishing industries and livelihoods, from which people derive material assets (**Box 4.10**), although some of these adaptations may not have been the preferred option for some local communities (**section 4.6**). *Cyprius carpio* is also listed as a top 10 species causing negative impacts on good quality of life (**Table 4.21**).

Three other invasive alien species that provide benefits to people are *Equus ferus* (wild horse), *Eucheuma denticulatum* (eucheuma seaweed), and *Columba livia* (pigeons). Wild horses are considered by some groups of people as a culturally-important species and thus benefit social and cultural relations (Collin, 2017), *Eucheuma denticulatum* contains medicinal properties, and *Columba livia* is used as a food source by local communities.

**Table 4.23.** Main invasive alien species causing positive impacts on good quality of life

The top 10 (by number of documented impacts) invasive alien species causing positive impacts on good quality of life. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

Plants:  Vertebrate: 

| **Invasive alien species** | **Taxa** | **Frequency of positive impacts documented for constituents of good quality of life** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Assets** | **Health** | **Relations** | **Safety** | **Freedom** | **Total** |
| *Robinia pseudoacacia* (black locust) |  | 30 | 0 | 8 | 8 | 0 | 46 |
| *Prosopis juliflora* (mesquite) |  | 10 | 0 | 0 | 4 | 0 | 14 |
| *Pontederia crassipes* (water hyacinth) |  | 7 | 6 | 0 | 1 | 0 | 14 |
| *Columba livia* (pigeons) |  | 10 | 0 | 0 | 0 | 0 | 10 |
| *Equus ferus* (wild horse) |  | 0 | 0 | 6 | 0 | 1 | 7 |
| *Cyprinus carpio* (common carp) |  | 6 | 0 | 0 | 0 | 0 | 6 |
| *Eucheuma denticulatum* (eucheuma seaweed) |  | 6 | 0 | 0 | 0 | 0 | 6 |
| *Oreochromis mossambicus* (Mozambique tilapia) |  | 6 | 0 | 0 | 0 | 0 | 6 |
| *Oreochromis niloticus* (Nile tilapia) |  | 6 | 0 | 0 | 0 | 0 | 6 |
| *Ailanthus altissima* (tree-of-heaven) |  | 4 | 0 | 2 | 0 | 0 | 6 |

## 4.5.1.1. Invasive alien ants impact multiple constituents of good quality of life

Invasive alien ants are a group of invasive alien species with a high number of impacts documented across multiple constituents of good quality of life, particularly affecting human health, more so than material assets. Invasive ants have been well-studied in terms of socio-economic impacts (Gruber et al., 2022). Using the SEICAT (**Box 4.2**), 550 socio-economic impacts of invasive ants have been documented for 65 named species in 50 countries and territories, with most documented impacts from the United States (36 per cent), Brazil (22 per cent), Australia (5 per cent) and Malaysia (5 per cent). The most frequently identified socio-economic impacts are on health (60.6 per cent of documented impacts) and material assets (35.1 per cent). The remaining impacts are on social (4.7 per cent), spiritual (0.4 per cent), and cultural relations (2.4 per cent) and non-material assets (1.9 per cent). Health impacts (269/279 documented impacts) are predominantly from stings and bites, and some deaths have also been documented.

Vectoring of pathogens in hospitals and food preparation facilities have been considered minor health impacts. Effects on material assets are mostly electrical damage from ants nesting in appliances and infrastructure, and damage to crops and livestock that affected livelihoods, also usually to a minor degree (128 out of 153 documented impacts). Impacts on non-material assets and social, spiritual, and cultural relations include avoidance of outdoor activities and health effects on pets. Under the SEICAT methodology, which categorizes a species based on the highest magnitude of documented impact, *Wasmannia auropunctata* (little fire ant) poses the most serious socio-economic threat (massive impact as determined by permanent disappearance of an activity), followed by *Solenopsis invicta* (red imported fire ant) and *Anoplolepis gracilipes* (yellow crazy ant). However, these highest categorizations were each based on a single record only. Of these three species, *Anoplolepis gracilipes* is the most widespread having a pan-tropical distribution. The introduced range of *Wasmannia auropunctata* is predominantly in the Caribbean, but also includes some islands in the Pacific, eastern Australia, western Africa, southern United States, and in Europe and northern America. *Solenopsis invicta* has been introduced to the southern United States, the Caribbean, China, Japan, and Australia. All other species are ranked as having, at most, moderate impacts (changes in activity size, switching or moving activities) or minor impacts (difficult to carry out normal activities).

### 4.5.1.2. Small island states and the impact of invasive alien species on good quality of life

One fifth of the documented impacts (20.5 per cent, 776 impacts) of invasive alien species on good quality of life are found in island states. Among these, 76.5 per cent (594) are negative impacts, and 23.5 per cent (182) are positive impacts (**Figure 4.40**). While the proportion of negative to positive impact cases in the islands is about 3.3 (594/182), this figure for the mainlands is about 6.7 (2614/394), suggesting positive impacts on good quality of life are proportionally higher in islands than on mainland. These numbers suggest that island ecosystems and good quality of life in islands are vulnerable to invasive alien species and their impacts (D'Antonio & Dudley, 1995; **section 4.3.1.1**). Both positive and negative impacts are primarily documented on material and immaterial assets, such as food production in agriculture, followed by health and relations. About half of the positive impacts of good quality of life in health and relations (52 of 111 cases, and 52 of 97 cases, respectively) are documented from island states. Islands tend to lack some of the species that can be beneficial for human uses, and thus inhabitants introduced alien species to improve their good quality of life. This could explain why positive impacts on good quality of life are documented at a higher rate from islands. For the same reason, agriculture introductions are the major pathway of invasive alien species introduction in island states (Driscoll et al., 2014). This probably leads to the proportionally larger number of documented cases in cultivated lands. Documented impact across units of analysis in islands are disproportionally distributed: while the number of documented negative impact cases from dry land in islands is equal to the mainlands (201 and 214), there are only 4 cases from boreal forest as opposed to 292 cases in mainlands. This is probably because studied islands are predominantly biased to the tropics in the Asia-Pacific region. Indeed, 70.2 per cent of the documented impacts on good quality of life in islands are found in Asia-Pacific, although Asia-Pacific represents 40.9 per cent of all documented impacts on good quality of life. Invertebrates have caused 55.4 per cent of negative and 46.7 per cent positive impacts on the good quality of life in islands, while this figure is 50 per cent and 28.9 per cent in mainlands. While plants are the largest group with positive impacts in mainlands, invertebrates are the largest group with positive impacts in islands.

In islands, two aquatic plant species, *Pontederia crassipes* (water hyacinth) and *Salvinia × molesta* (kariba weed), are the major species that reduce good quality of life through compromising assets and health constituents, followed by *Lissachatina fulica* (giant African land snail), Dengue virus, and *Laevicaulis alte* (tropical leatherleaf slug). Among invertebrates, molluscs are the major invasive alien species groups that provide positive impacts on good quality of life in islands. *Lissachatina fulica* and *Laevicaulis alte* are the two most documented invasive alien species from islands causing both positive and negative impacts. They are major agriculture pests (Cowie et al., 2009) as well as intermediate hosts for various parasites, such as *Angiostrongylus cantonensis* (rat lungworms; Barratt et al., 2016). At the same time, those molluscs were documented to positively impact assets and health through predating invasive alien molluscs or transmitting parasites to their final hosts, such as invasive alien rats (Nurinsiyah & Hausdorf, 2019). Studies on the positive impacts of invasive alien species on good quality of life are still limited, and information on the positive impacts caused by molluscs is based on a single study (Nurinsiyah & Hausdorf, 2019).

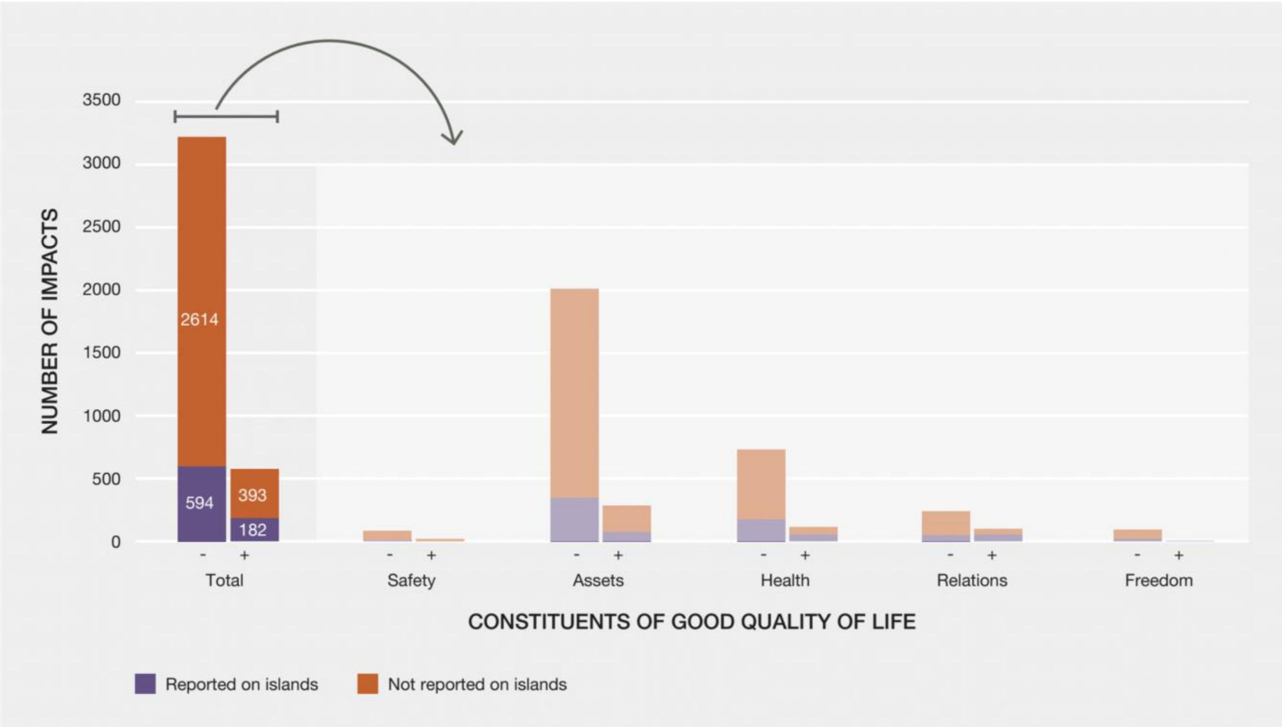


**Figure 4.40.** Number of impacts (y axis) of invasive alien species on constituents of good quality of life (x axis) in islands and in mainlands. This figure shows the number of negative (-) and positive (+) impacts on good quality of life in islands and in other locations globally, and for each constituent of good quality of life. A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

### 4.5.1.3. Direct and indirect impacts on human health

Invasive alien species negatively impact human health, from nuisance to allergies, poisoning, disease and death (Martinou & Roy, 2018; **Figure 4.41**; **Box 4.15**).

The widely dispersed agricultural and garden pest *Lissachatina fulica* (giant African land snail; **Figure 4.42**) serves as the intermediate host of a parasitic nematode, *Angiostrongylus cantonensis* (rat lungworm). Human infection with its larvae, through handling or consumption, causes eosinophilic meningitis, which may result in cranial nerve abnormalities, ataxia, encephalitis, coma, and, rarely, death (Kwon et al., 2013; Malvy et al., 2008; Thiengo et al., 2010; Tsai et al., 2001). The aggressive and venomous invasive alien ant *Solenopsis invicta* (red imported fire ant; **Figure 4.42**), introduced from Brazil to the southern United States, Caribbean, East Asia, and Australia, represents a significant health hazard. Its venom induces an immediate, severe burning sensation; subsequent reactions may range from local pustules and rash to life-threatening anaphylaxis (deShazo et al., 1990, 1999; deShazo & Banks, 1994; Stafford, 1996; Xu et al., 2012; Zhang et al., 2007). Incidence of fatalities attributed to fire ant-induced anaphylaxis have been rare to none in the southeastern United States (Prahlow & Barnard, 1998; Rhoades et al., 1989). Between 30 and 60 per cent of the population in urban areas infested by imported fire ants are stung every year (deShazo et al., 1990).

**Box 4.15. Direct and indirect impacts of invasive alien species on human health**

Invasive alien species occasionally have deleterious impacts on human health, presenting serious challenges to the good quality of life (**Chapter 1**, **section 1.6.7.2**). They can affect physical as well as psychological health (Martinou & Roy, 2018), directly (e.g., injury to people) or indirectly (e.g., through a reduction in food security). Their role as disease vectors is discussed in **Box 4.16**.

In the terrestrial realm, biological invasions are directly affecting people. There are many invasive alien terrestrial plants with highly allergenic pollen, including *Ambrosia artemisiifolia* (common ragweed), native to Central and Northern America but now found throughout the world, and the dermatitis-causing *Heracleum mantegazzianum* (giant hogweed), native to southern Russia and Georgia but now spread through northern Europe (Jakubska-Busse et al., 2013; Klimaszyk et al., 2014; Lim et al., 2021). *Solenopsis invicta* (red imported fire ant), invasive in North America since the 1930s, inflicts severe stings and has killed people with allergies to its venom (Jemal & Hugh-Jones, 1993). Invasive alien snakes were introduced in Guatemalan oil palm plantations to limit rodent populations, and have bitten local children living nearby, forcing families to relocate (IPBES, 2020). Invasive agricultural pests can also indirectly affect human health by reducing food security; for example, the income and nutrition of small holder farmers and their families involved in mixed maize farming in east Africa is hampered by several major invasive alien species, including *Chilo partellus* (spotted stem borer) and viruses causing Maize Lethal Necrosis Disease (C. F. Pratt et al., 2017). *Spodoptera frugiperda* (fall armyworm) has been described as an "emerging food security global threat" by the Food and Agricultural Organization of the United Nations (FAO) and International Plant Protection Convention; its impact has been painfully evident in countries facing other severe challenges to public health and governance, such as the Democratic Republic of the Congo, Sudan, and Yemen (FAO, 2018). Food security is tightly linked to invasive alien species management in China (McBeath & McBeath, 2010) and wheat-producing countries such as the United States and Canada need to protect against a variety of pernicious invasive alien species such as *Trogoderma granarium* (khapra beetle), one of the world's worst storage pests (Athanassiou et al., 2019).

In inland waters, the shells of *Dreissena polymorpha* (zebra mussel) can cause skin injuries to recreational swimmers and commercial fishers. *Pontederia crassipes* (water hyacinth) can make small-scale freshwater fishing next to impossible, indirectly lowering income, food security, and nutrition levels for local communities. Moreover, its introduction has been implicated in the spread of malaria in Lake Victoria due to the creation of habitat for the mosquitoes that harbour *Plasmodium* parasites (Kasulo & Perrings, 2000).

In the marine realm, venomous and poisonous invasive alien species include *Plotosus lineatus* (striped eel catfish) and *Lagocephalus sceleratus* (silver-cheeked toadfish), urchins and jellyfish (Galanidi et al., 2018; Galil, 2018; **Figure 4.41**).

**Figure 4.41**. Injuries inflicted by the invasive jellyfish Rhopilema nomadica (nomad jellyfish). *Rhopilema nomadica* are invasive alien species found in the Mediterranean Sea. Their stings impact good quality of life in this area. Photo credit: Moti Mendelson – CC BY 4.0.

Combined with other threats to good quality of life described elsewhere in this assessment, invasive alien species directly and indirectly present formidable challenges to human health, in the midst of climate change (Schindler et al., 2018). Awareness of the extent of the threat posed to human health by invasive alien species is still limited. Studies on the impacts of invasive alien species on mental health impacts are also emerging. For example, a participant in an IPBES Indigenous and local knowledge workshop and a formal study both suggest there has been a noticeable decrease in "subjective well-being" due to the impacts of the invasive *Agrilus planipennis* (emerald ash borer) in North America (IPBES, 2020; B. A. Jones, 2017; **Box 4.18**).

Many vector-borne pathogens have appeared in the past few decades in new regions as result of introductions, some causing explosive epidemics (Kilpatrick & Randolph, 2012; **Box 4.16**). Zoonotic diseases transmitted by invasive mosquito genera (e.g., *Aedes*, *Anopheles*, *Culex*) include malaria, dengue fever, chikungunya, Zika, yellow fever, and West Nile fever, and inflict misery, chronic symptoms, and occasionally death (M. R. Duffy et al., 2009; Effler et al., 2005; Enserink, 2006; Fares et al., 2015; Heukelbach et al., 2016; Kilpatrick, 2011; Laras et al., 2005; Nash et al., 2001; Polwiang, 2020; Rezza et al., 2007; N. Singh et al., 2015). Several widely dispersed plant species (e.g., *Prosopis juliflora* (mesquite), *Parthenium hysterophorus* (parthenium weed)) significantly contribute to *Anopheles* mosquito longevity, and thereby enhance malaria transmission potential (Muller et al., 2017; Nyasembe et al., 2015; Tyagi et al., 2015).

**Box 4.16. Invasive alien species as disease vectors or reservoir hosts**

Beyond the health impacts discussed in **Box 4.15**, many invasive alien species can act as disease vectors (i.e., introducing parasites and pathogens to new regions along with their host, passing diseases directly to humans), reservoir hosts (where a disease can survive before a vector passes it onward), or facilitators (i.e., helping the occurrence of pathogen or vector).

Global trade in livestock, wildlife and plants is a key driver facilitating both intended and unintended introductions of pathogens, hosts, and vectors to new land areas, increasing the rate of disease emergence and health impacts on human populations (Bezerra-Santos et al., 2021; Chinchio et al., 2020; Fèvre et al., 2006; Lounibos, 2002; Vilà et al., 2021).

Diseases such as the bubonic plague, caused by the flea- and rat-borne bacterium *Yersinia pestis* (black death), have caused traumatic social and political upheavals (Athni et al., 2021; Kosoy & Bai, 2019; Wells et al., 2015). Mosquito species such as *Aedes aegypti* (yellow fever mosquito*)* and *Aedes albopictus* (Asian tiger mosquito) have spread since the fifteenth century, largely due to shipping, air and road transport and trade (Lounibos, 2002). These species have exacerbated the spread of the lethal yellow fever, dengue fever, chikungunya and Zika viruses, and other infectious diseases, throughout the Americas, Asia and, more recently Europe (Juliano & Lounibos, 2005; LaPointe, 2021; Romi et al., 2018). *Culex quinquefasciatus* (southern house mosquito), a vector for lymphatic filariasis, St. Louis Encephalitis virus, and West Nile virus, has spread from West Africa, killing over a million people a year (LaPointe, 2021; Lounibos, 2002; Romi et al., 2018). Invasive mammals and birds can alter the epidemiology of resident pathogens and become reservoir hosts, increasing disease risk for humans (Capizzi et al., 2018). Most zoonotic human diseases are known to originate from mammals: rodents and bats are vectors for a high number of pathogens (Han et al., 2016), and so are *Nyctereutes procyonoides* (raccoon dog), implicated in rabies and tapeworm transmission, and *Procyon lotor* (raccoon), implicated in roundworm transmission (Lojkić et al., 2021; Page et al., 2016). Introduced bird species, in particular psittaciform (parrots), columbiform (pigeons) and anseriform (duck) species, represent a hazard to good quality of life. Main zoonoses include psittacosis, cryptococcosis, listeriosis and salmonellosis, transmitted by direct contact or via insect vectors (fleas, lice, ticks and mites). Some galliform species, introduced for hunting, can cause salmonellosis and other gastroenteric diseases (Mori et al., 2018).

The magnitude of risks and impacts arising from co-invasive pathogens is difficult to discern because few data exist on the links among invasive alien species, their parasites or pathogen load and zoonotic diseases (Hulme, 2014). Robust documentation of the prevalence and abundance of parasites, pathogens, and vectors of human diseases associated with high-risk alien hosts would be needed to initiate effective management.

Some of the most widely dispersed invasive alien plants cause direct or indirect adverse effects. *Hedera helix* (ivy), native to Europe, is established in Australia, New Zealand, Hawaii, Brazil, and North America, where it causes allergic contact dermatitis (Bregnbak et al., 2015; J. M. Jones et al., 2009). The pollen of *Ambrosia artemisiifolia* (common ragweed), a native plant to Central and Northern America that has spread widely, is a common seasonal source of aeroallergens, and a major concern for public health, causing allergic rhinitis, fever, or dermatitis (Déchamp, 1999; Möller et al., 2002). A single *Ambrosia artemisiifolia* plant can indeed release up to one billion pollen grains per season, and as low as 10 pollen grains per cubic meter of air can trigger an allergic reaction (DellaValle et al., 2012; Emberlin, 1994; Fumanal et al., 2007). High pollen exposure or volume may lead to increases in sensitization rate (Gabrio et al., 2010; Jäger, 2000). *Prosopis juliflora* (mesquite) pollen also elicits highly allergenic reactions (Al-Frayh et al., 1999; Ezeamuzie et al., 2000; Kathuria & Rai, 2021; Killian & McMichael, 2004). *Heracleum mantegazzianum* (giant hogweed), native to southern Russia and Georgia but now spread throughout northern Europe, poses threats to human health due to its photoallergic properties, resulting from the intensely toxic furanocoumarin in its sap (**Figure 4.42**). Contact with the plant, followed by sun exposure, may lead to the development of blisters and symptoms of burns (Carlsen & Weismann, 2007; Jakubska-Busse et al., 2013; Klimaszyk et al., 2014; Lim et al., 2021).

Health impacts caused by invasive alien marine species have been amply documented. In the Mediterranean Sea, for example, the venomous *Rhopilema nomadica* (nomad jellyfish; **Figure 4.42**), *Pterois miles* (lionfish), and the lethally poisonous *Lagocephalus sceleratus* (silver-cheeked toadfish) present well-known dangers (Galil, 2018). With rising seawater temperature, it is likely these thermophilic species will expand their range. Though published records attest to the increasing spread and abundance of these species in the Mediterranean Sea, only fragmentary information is available concerning the spatial and temporal trends (**Glossary**) of their impacts (Bédry et al., 2021; Galil, 2018). Even for common, wide-spread species with acute symptoms such as *Lagocephalus sceleratus* and *Rhopilema nomadica*, incidents are poorly documented. Öztürk and İşinibilir (2010) reported that in summer 2009, nomad jellyfish envenomation caused 815 hospitalizations in Turkey, but no data is available for other years and other locations. A similar pattern emerges from the records of toadfish poisoning, reported mainly in local journals and digital media (Ben Souissi et al., 2014).The lack of region-wide, quantitative data on medically-treated health impacts could lead on one hand to medical errors (Beköz et al., 2013), and on the other, prejudice risk analyses undertaken by management. Incidents involving large numbers of patients may be expected to become more frequent with changing environmental conditions, unless this becomes a public health priority (Glatstein et al., 2018).

**Figure 4.42.** Examples of invasive alien species causing serious health problems. *Lissachatina fulica* (giant African land snail, top left), *Solenopsis invicta* (red imported fire ant, top right), *Heracleum mantegazzianum* (giant hogweed, bottom left), *Rhopilema nomadica* (nomad jellyfish, bottom right). Photo credits: Mark Brandon, Shutterstock – Copyright (top left) / Alexander Wild, WM Commons – Public domain (top right) / MurielBendel, WM Commons – CC BY-SA 4.0 (bottom left) / Jimmy, Adobe Stock – Copyright (bottom right).

### 4.5.1.4. Impacts on human health: links with impacts on other constituents of good quality of life

Constituents of good quality of life are often linked, and impacts on human health are one type of impacts on other constituents of good quality of life. Many Indigenous Peoples and local communities experience these connections acutely due to their close physical and spiritual interactions with the environment (**Box 4.17**). Many invasive alien species impact Indigenous Peoples and local communities' lifestyles, by restricting access to lands and participation in traditional activities (IPBES, 2020). For example, in Australia, *Anoplolepis gracilipes* (yellow crazy ant) and *Solenopsis invicta* (red imported fire ant), which can bite people, have prevented some Indigenous Peoples and local communities from taking part in traditional activities. *Pastinaca sativa* (parsnip), an invasive alien plant in Canada, has been documented by Indigenous Peoples and local communities to cause skin to become sensitive to sunlight, burning the skin, which is a problem for hunters of that community (IPBES, 2020). The increase of Lyme disease-bearing *Ixodes scapularis* (blacklegged or deer ticks) populations in Canada is indirectly impacting knowledge transmission as Indigenous Peoples and local communities are concerned about taking children out on the land, where the majority of Indigenous and local knowledge learning takes place

(IPBES, 2020). Indigenous Peoples and local communities in Siberia have known that *Heracleum pubescens* (Sosnowskyi's hogweed or Borshchievik in Russian) has been a problem for them since the 1980s (IPBES, 2020); they report that it is highly poisonous when over 60cm high and seeding, with stems and leaves causing allergic reactions, severe dermatitis and may cause cancerous tumours, congenital malformations and even fatalities in humans and animals (IPBES, 2020). Indigenous Peoples and local communities often try to maintain access to land and carry out traditional activities, particularly passing knowledge onto the next generation. When invasive alien species impact upon these activities, this can lead to "cultural erosion" (Pfeiffer & Voeks, 2008), whereby knowledge, particularly names of native species, their habitats, and their cultural values and stories are not passed down to younger people, which can have negative implications for the good quality of life of future generations (Robin et al., 2022; **Box 4.17**).

**Box 4.17. The impacts on cultural species, cultural sites, cultural relationships and health of Indgenous peoples and local communities, revealed through Indigenous and local knowledge and cross-cultural research in Australia's Northern Territory**

Cross-cultural research (using methodologies from different knowledge systems), was used in Arnhem Land, at the northeast corner of Australia's Northern Territory, to investigate invasive ungulates (buffalo, donkeys, pigs, cattle and horses) trampling and grazing on traditional bush food resources and impacting water quality at several culturally significant wetlands.

Wetlands provide Indigenous Peoples with drinking water, medicines and bush foods, including *Eleocharis dulcis* (Chinese water chestnut) and *Nymphaea* spp. (water lilies), and is host to aquatic fauna, including *Chelodina rugosa* (northern snake-necked turtle), which is an important seasonal source of protein (Fordham et al., 2006; Ens, Fisher, et al., 2015). The Indigenous People of Ngukurr, Arnhem Land, have raised concerns about drinking water from wetlands due to potential microbial contamination from feral invasive ungulates, yet deoxyribonucleic acid (DNA) analysis for the waterborne pathogens *Cryptosporidium* and *Giardia* revealed the latter was only detected in the late dry season and former was not detected at all (S. Russell et al., 2021). The presence of invasive ungulates negatively impacts on indigenous access to bush food, medicine and freshwater resources which then reduces opportunities for cultural and spiritual practices (S. Russell et al., 2020, 2021). For example, hooved ungulates damage *Chelodina rugosa* aestivating over the dry season (S. Russell et al., 2021), and feral pig predation depletes turtle stocks immediately before Aboriginal harvesting (Fordham et al., 2006). An Indigenous knowledge holder described an eco-cultural regime shift of a wetland ecosystem from a water lily (*Nymphaea violacea* and *Nymphaea macrosperma*) dominated system to a turbid, sediment dominated system. This was attributed to human depopulation of traditional lands and waters and the subsequent invasion by feral ungulates. Evidence for this "regime shift" is based on Indigenous ecological knowledge (S. Russell et al., 2021). Transformation of this ecosystem has had implications for access to bush food resources; *Nymphaea* spp. Roots, stems, and bulbs that were a staple food for local Indigenous Peoples.

Although invasive ungulates are impacting ecological condition, indigenous cultural practice, and potentially human health, these animals present a significant food source and potential source of income to remote living Indigenous Peoples and local communities who have low socio-economic status (C. J. Robinson et al., 2005). The conflicting impacts and benefits of these invasive alien species has meant that widespread and sustained control has not occurred across northern Australia. To accommodate the multiple values of these invasive alien species, at present, members of the Ngukurr community prefer maintenance of multi-functional landscapes where the multiple values of these species can be supported (Ens, Fisher, et al., 2015). However, with economic development of this region, support of invasive ungulate management may increase (**Figure 4.43**).

**Figure 4.43.** Invasive ungulates pollute wetlands in Australia's Northern Territory; and indigenous rangers document the impacts on water quality and cultural species, including *Nymphaea* spp. (water lilies). Photo credit: Shaina Russell – CC BY 4.0.

### 4.5.2. Documented impacts of invasive alien species on good quality of life by realm

Impacts of invasive alien species on good quality of life vary by realm and unit of analysis. As a general pattern, the impact database developed through this chapter reveals that impacts are most often experienced through changes to material and immaterial assets, followed by impacts on health and social and cultural relationships.[14] Impacts on safety and freedom of choice and action are the two least documented components of good quality of life.

Notably, a small number of the units of analysis account for most of the impacts on good quality of life (**sections 4.5.2.1** and **4.5.2.2**). Among the documented negative impacts, 74 per cent occur in cultivated areas (including cropping, intensive livestock farming, etc.; 935 negative impacts caused by 332 invasive alien species), urban/semi-urban (606 negative impacts caused by 245 invasive alien species), inland surface water and water bodies/freshwater (411 negative impacts caused by 151 invasive alien species), and tropical and subtropical dry and humid forests (415 negative impacts caused by 136 invasive alien species). Similarly, 74 per cent of all positive impacts occur in cultivated areas (151 positive impacts caused by 79 invasive alien species), tropical and subtropical dry and humid forests (118 positive impacts caused by 70 invasive alien species), temperate and boreal forests and woodlands (82 positive impacts caused by 40 invasive alien species), and inland surface water and water bodies/freshwater (80 positive impacts caused by 49 invasive alien species). Examining positive impacts helps put these percentages into perspective. The three least affected units of analysis with positive impacts, tundra and high mountain habitats (5 positive impacts, caused by 2 invasive alien species), Mediterranean forests, woodlands and scrub (2 positive impacts caused by 2 invasive alien species), and open ocean pelagic systems (1 positive impact caused by 1 invasive alien species), make up less than 2 per cent of all positive documented impacts. **Table 4.24** presents the main invasive alien species causing impacts on good quality of life in each unit of analysis.

**Table 4.24.** Invasive alien species most frequently documented to cause negative or positive impacts on good quality of life by unit of analysis

A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

Plants:  Invertebrate: 

[14] Data management report available at: https://doi.org/10.5281/zenodo.5766069

Vertebrate: Microorganisms:

| Unit of analysis | List of invasive alien species with negative impacts on good quality of life (# of observations) | List of invasive alien species with positive impacts on good quality of life (# of observations) |
|---|---|---|
| Tropical and subtropical dry and humid forests | Dengue virus (76) | *Subulina octona* (thumbnail awlsnail) (9) |
| | *Lissachatina fulica* (giant African land snail) (36) | *Gulella bicolor* (two-tone gulella) (8) |
| | *Laevicaulis alte* (tropical leatherleaf slug) (11) | *Allopeas clavulinum* (Spike awlsnail) (7) |
| | | *Allopeas gracile* (Graceful awlsnail) (7) |
| | | *Bradybaena similaris* (Asian trampsnail) (7) |
| | | *Deroceras leave* (meadow slug) (7) |
| | | *Gastrocopta servilis* (wandering snag) (7) |
| | | *Geostilbia aperta* (obtuse awlsnail) (7) |
| | | *Guppya gundlachi* (glossy granule) (7) |
| Temperate and boreal forests and woodlands | *Agrilus planipennis* (emerald ash borer) (35) | *Equus ferus* (wild horse) (4) |
| | *Phytophthora ramorum* (sudden oak death) (34) | *Cervus nippon* (sika) (2) |
| | *Hymenoscyphus fraxineus* (ash dieback) (25) | *Corythucha arcuata* (oak lace bug) (3) |
| Mediterranean forests, woodlands and scrub | *Xylella fastidiosa* (Pierce's disease of grapevines) (15) | *Agave americana* (century plant) (1) |
| | *Ceratocystis platani* (canker stain of plane) (13) | |
| | *Seiridium cardinale* (cypress canker) (11) | |
| Tundra and High Mountain habitats | *Conium maculatum* (poison hemlock) (1) | *Equus ferus* (wild horse) (4) |
| | *Pinus* spp. (pine) (1) | *Melilotus albus* (honey clover) (1) |
| | *Equus ferus* (wild horse) (1) | |
| Tropical and subtropical savannas and grasslands | *Corvus splendens* (house crow) (9) | *Acacia mearnsii* (black wattle) (1) |
| | *Acacia mangium* (brown salwood) (3) | *Centaurea solstitialis* (yellow starthistle) (1) |

| | | | | |
|---|---|---|---|---|
| | | *Cenchrus biflorus* (Indian sandbur) (3) | | *Hyparrhenia rufa* (jaragua grass) (1) |
| | | | | *Prosopis juliflora* (mesquite) (1) |
| | | | | *Tithonia* spp. (1) |
| Temperate Grasslands | | *Lonchura oryzivora* (Java sparrow) (10) | | *Sporobolus anglicus* (common cordgrass) (1) |
| | | *Acridotheres tristis* (common myna) (8) | | *Rosa rugosa* (rugosa rose) (8) |
| | | *Corvus splendens* (house crow) (8) | | *Bombus terrestris* (bumble bee) (1) |
| | | | | *Columba livia* (pigeons) (10) |
| | | | | *Alces alces* (moose) (1) |
| | | | | *Bos taurus* (cattle) (1) |
| | | | | *Capra hircus* (goats) (1) |
| | | | | *Cervus elaphus canadensis* (elk) (1) |
| | | | | *Cervus elaphus* (red deer) (1) |
| Deserts and xeric shrublands | | *Cenchrus ciliaris* (buffel grass) (7) | | *Prosopis juliflora* (mesquite) (9) |
| | | *Prosopis* spp. (5) | | *Opuntia* spp. (pricklypear) (2) |
| | | *Camelus* spp. (camels) (4) | | *Prosopis glandulosa* (honey mesquite) (2) |
| Urban/Semi-urban | | *Solenopsis invicta* (red imported fire ant) (38) | | *Columba livia* (pigeons) (10) |
| | | *Lissachatina fulica* (giant African land snail) (32) | | *Corvus splendens* (house crow) (2) |
| | | *Monomorium pharaonis* (pharaoh ant) (16) | | *Sarasinula plebeia* (Caribbean leatherleaf slug) (7) |
| | | | | *Trichocorixa verticalis* (water boatman) (2) |
| Cultivated areas (incl. cropping, intensive livestock farming etc.) | | *Spodoptera frugiperda* (fall armyworm) (46) | | *Columba livia* (pigeons) (10) |
| | | *Bactrocera dorsalis* (Oriental fruit fly) (40) | | *Subulina octona* (thumbnail awlsnail) (9) |
| | | *Phenacoccus manihoti* (cassava mealybug) (35) | | *Gulella bicolor* (two-tone gulella) (8) |
| Aquaculture areas | | *Cyprinus carpio* (common carp) (7) | | *Azolla filiculoides* (water fern) (1) |

| | | | | |
|---|---|---|---|---|
| | | *Oreochromis niloticus* (Nile tilapia) (6) | | *Oreochromis mossambicus* (Mozambique tilapia) (3) |
| | | *Hypophthalmichthys molitrix* (silver carp) (4) | | *Clarias gariepinus* (North African catfish) (1) |
| | | *Oreochromis mossambicus* (Mozambique tilapia) (4) | | *Oreochromis niloticus* (Nile tilapia) (1) |
| | | | | *Poecilia reticulata* (guppy) (1) |
| Wetlands – peatlands, mires, bogs | | *Elaeagnus angustifolia* (Russian olive) (3) | | *Trichocorixa verticalis* (water boatman) (2) |
| | | *Acridotheres tristis* (common myna) (2) | | *Acridotheres javanicus* (Javan myna) (2) |
| | | *Threskiornis aethiopicus* (sacred ibis) (2) | | *Threskiornis aethiopicus* (sacred ibis) (2) |
| Inland surface waters and water bodies/freshwater | | *Dreissena polymorpha* (zebra mussel) (19) | | *Oreochromis niloticus* (Nile tilapia) (6) |
| | | *Cyprinus carpio* (common carp) (19) | | *Oreochromis mossambicus* (Mozambique tilapia) (5) |
| | | *Oreochromis niloticus* (Nile tilapia) (14) | | *Lates niloticus* (Nile perch) (4) |
| | | | | *Procambarus clarkii* (red swamp crayfish) (4) |
| Shelf ecosystems (neritic and intertidal/littoral zone) | | *Rhopilema nomadica* (nomad jellyfish) (10) | | *Eucheuma denticulatum* (eucheuma seaweed) (7) |
| | | *Gonionemus* spp. (4) | | *Kappaphycus alvarezii* (elkhorn sea moss) (3) |
| | | *Lagocephalus sceleratus* (silver-cheeked toadfish) (5) | | *Paralithodes camtschaticus* (red king crab) (2) |
| | | *Plotosus lineatus* (striped eel catfish) (4) | | |
| Open ocean pelagic systems (euphotic zone) | | *Pterois* spp. (3) | | *Pterois* spp. (1) |
| Coastal areas intensively used for multiple purposes by humans | | *Dreissena polymorpha* (zebra mussel) (10) | | *Corbicula fluminea* (Asian clam) (2) |
| | | *Asterias amurensis* (northern Pacific seastar) (3) | | *Petromyzon marinus* (sea lamprey) (2) |
| | | *Dreissena rostriformis bugensis* (quagga mussel) (3) | | *Salmo trutta* (brown trout) (2) |

| | | | | |
|---|---|---|---|---|
| | | *Petromyzon marinus* (sea lamprey) (3) | | |

### 4.5.2.1. Patterns of negative and positive impacts of invasive alien species on good quality of life in the terrestrial realm

The terrestrial realm accounts for most of the documented impacts on good quality of life compared to aquatic realms; with 82 per cent (2,629 impacts) of all negative impacts and 81 per cent (467 impacts) of positive impacts. This is consistent with the literature on impacts of invasive alien species on livelihood, which indicates that a greater proportion of studies focused on terrestrial ecosystems have been conducted in savanna and woodland environments compared to freshwater ecosystems (R. T. Shackleton, Shackleton, et al., 2019).

**Most impacted units of analysis in the terrestrial realm**

Cultivated areas have the highest number of documented invasive alien species (332) and negative impacts (935) (**Table 4.25**). This pattern may be attributed in part to the greater attention paid to cultivated areas in research, given the critical role of food security in meeting basic human needs. Additionally, the ease of measuring human access to food in cultivated areas may make them a more accessible unit of analysis than other ecosystems (P. L. Howard, 2019; Pimentel et al., 2005). Large numbers of invasive alien species have also been documented in urban/semi-urban areas (245 invasive alien species), tropical and subtropical dry and humid forests (136 invasive alien species), and temperate and boreal forests and woodlands (101 invasive alien species), which, together, round out the top four affected units of analysis, accounting for 83 per cent of all documented negative impacts in the terrestrial realm. Tundra and high mountain habitats and deserts and xeric shrublands are the least affected units of analysis, and only host 5 per cent of the documented invasive alien species causing negative impacts on good quality of life in the terrestrial realm.

Material and immaterial assets are the most impacted constituent of good quality of life across units of analysis. However, in deserts and xeric shrublands, health is the dominant constituent negatively impacted by invasive alien species. There are very few documented impacts on safety across most units of analysis.

**Table 4.25.** Negative impacts on good quality of life in the terrestrial realm

Darker colours indicate higher documented numbers of invasive alien species or impacts. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

| | Material and immaterial assets | | Freedom of choice and action | | Health | | Social and cultural relationships | | Safety | |
|---|---|---|---|---|---|---|---|---|---|---|
| Unit of analysis | # species | # impacts | # species | # impacts | # species | # impacts | # species | # impacts | # species | # impacts |
| Tropical and subtropical dry and humid forests | 66 | 213 | 7 | 14 | 41 | 143 | 17 | 37 | 5 | 8 |
| Temperate and boreal forests and woodlands | 48 | 183 | 7 | 10 | 24 | 54 | 15 | 34 | 7 | 15 |
| Mediterranean forests, woodlands and scrub | 11 | 77 | 0 | 0 | 3 | 3 | 0 | 0 | 1 | 1 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tundra and High Mountain habitats | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| Tropical and subtropical savannas and grasslands | 18 | 33 | 4 | 4 | 20 | 28 | 13 | 21 | 2 | 2 |
| Temperate Grasslands | 54 | 103 | 0 | 0 | 12 | 32 | 3 | 4 | 0 | 0 |
| Deserts and xeric shrublands | 5 | 11 | 0 | 0 | 6 | 11 | 4 | 5 | 5 | 8 |
| Wetlands – peatlands, mires, bogs | 5 | 8 | 4 | 7 | 5 | 9 | 3 | 7 | 0 | 0 |
| Urban/Semi-urban | 111 | 299 | 2 | 3 | 89 | 240 | 31 | 48 | 12 | 16 |
| Cultivated areas (incl. cropping, intensive livestock farming etc.) | 224 | 730 | 21 | 26 | 56 | 129 | 22 | 38 | 9 | 12 |

**Invasive alien taxa most often documented causing negative impacts on good quality of life in the terrestrial realm**

The most prominent taxa negatively impacting good quality of life differ across units of analysis (**Table 4.24**). For example, cultivated areas, temperate grasslands, and urban/semi-urban areas are mainly affected by invasive alien animals such as *Spodoptera frugiperda* (fall armyworm) that causes significant damage to agriculture and rice crops (Kumela et al., 2019; **Box 4.18**). These species can create additional pressures for farmers in Africa or native American lands where the agricultural sector struggles to support farmers' livelihoods because of the lack of ownership, low or no financial capital, and increasing risks due to climate change (Gautam et al., 2013; P. L. Howard, 2019). Temperate grasslands contended with *Acridotheres tristis* (common myna) whose droppings can irritate people's skin and lungs (Peacock et al., 2007). Urban and semi-urban areas are most impacted by the aggressive *Solenopsis invicta* (red imported fire ant), whose powerful sting can cause injury and death to people, wildlife, and pets (Gutrich et al., 2007). Their ability to tunnel also impacts infrastructure, such as roads, power distribution systems, and irrigation systems (Gutrich et al., 2007). Impacts on good quality of life in Mediterranean forests, woodlands and scrub are mostly caused by microbes, such as *Xylella fastidiosa* (Pierce's disease of grapevines), known for killing olive trees (Schneider et al., 2020), reiterating that material and immaterial assets are the most affected component of good quality of life.

The remaining units of analysis experience impacts from several taxa. Tropical and subtropical dry and humid forests and temperate and boreal forests and woodlands are negatively affected by microbes and animals. Deserts and xeric shrublands, tropical and subtropical savannas and grasslands, tundra and high mountain, and wetland habitats contend with both plants and animals. In the deserts and xeric shrublands in Africa, *Prosopis* spp. (mesquite) threatens safety through impacts on personal safety and secure resource access as the invasion has forced large predators like lions to move closer to villages, leading to livestock and human deaths (P. L. Howard, 2019). There are no units of analysis exclusively impacted by plant species.

**Box 4.18. *Spodoptera frugiperda* (fall armyworm) – how impacts on nature's contributions to people and impacts of management affect good quality of life for Indigenous Peoples and local communities**

**Impacts on nature's contributions to people: crop losses**

A majority (61 per cent) of the studies reviewed[15] have documented that Indigenous Peoples and local communities suffer yield losses due to the invasion of *Spodoptera frugiperda* (fall armyworm). The crop yield loss estimates due to *Spodoptera frugiperda* range from 10 per cent in Malawi (Murray et al., 2019) to as high as 58 per cent in Zimbabwe (Chimweta et al., 2020; **Table 4.26**). Most of the yield loss estimates are related to maize production, but the FAO also found that *Spodoptera frugiperda* has caused 6 per cent and 2 per cent millet and sorghum production losses, respectively, at the national level in Namibia (FAO, 2018). There is also evidence suggesting that the yield loss estimates were higher in the early years of the *Spodoptera frugiperda* invasion. For instance, Day et al. (2017) found maize yield losses of 45 per cent and 40 per cent in Ghana and Zambia respectively (or 8.3 to 20.6 million tonnes annually in 12 African countries), but a follow-up study a year later by Rwomushana et al. (2018) showed maize yield losses of 26 per cent and 35 per cent in the two respective countries (or 4.1 to 17.7 million tonnes annually in 12 African countries). As noted by Rwomushana et al. (2018), this decline in yield losses could be due to build-up of natural enemies, climatic factors, improved management or the possibility that farmers are getting better at estimating *Spodoptera frugiperda*-induced yield loss. It should be mentioned that most of the yield loss estimates were based on farmers' perceptions, which may have overestimated true losses (Baudron et al., 2019) even when controlling for potential confounding factors in a regression framework, documented *Spodoptera frugiperda*-induced yield losses are nearly 12 per cent (Baudron et al., 2019; Kassie et al., 2020).

**Table 4.26.** Yield loss estimates due to *Spodoptera frugiperda* (fall armyworm) invasion

A data management report for the literature review underpinning this table is available at https://doi.org/10.5281/zenodo.5760266

| ***Study*** | ***Country*** | ***Yield loss estimates*** |
|---|---|---|
| Asare-Nuamah (2022) | Ghana | Massive (no exact estimate) |
| Bariw et al. (2020) | Ghana | 17.2 per cent |
| Baudron et al. (2019) | Zimbabwe | 11.6 per cent |
| Chimweta et al. (2020) | Zimbabwe | 58 per cent |
| Day et al. (2017) | Ghana and Zimbabwe | 45 per cent in Ghana; 40 per cent in Zambia (extrapolated to up to 20.6 million tonnes annually in 12 Africa countries) |
| De Groote et al. (2020) | Kenya | 33 per cent or 1 million tonnes |
| FAO (2018) | Namibia | 14 per cent of maize (8 per cent in communal areas and 6 per cent in commercial farms); 6 per cent of millet; 2 per cent of sorghum |
| Turot et al. (2019) | Tanzania | 10.8 per cent at area level; 15.8 per cent at farm level |
| Girsang et al. (2020) | Indonesia | 26.6 per cent |
| Houngbo et al. (2020) | Benin | 49 per cent |
| Kansiime et al. (2019) | Zambia | 28 per cent |
| Kassie et al. (2020) | Ethiopia | 11.5 per cent |
| Koffi et al. (2020) | Ghana | 132,450 tons in 2016; 180,000 tons in 2017; 36,000 tons in 2018 |

[15] Data management report available at: https://doi.org/10.5281/zenodo.5760266

| | | |
|---|---|---|
| Kumela et al. (2019) | Ethiopia and Kenya | 46.5 per cent in Ethiopia; 38.8 per cent in Kenya |
| Mayee et al. (2021) | India | Decline in maize area from 9.2 million ha in 2018 to 8.2 million ha in 2019 (no exact estimate) |
| Murray et al. (2021) | Kenya | Up to 50 per cent |
| Murray et al. (2019) | Malawi | 10 per cent |
| Nyangau et al. (2020) | Kenya and Uganda | No exact estimate |
| Rwomushana et al. (2018) | Ghana and Zambia | 26 per cent in Ghana; 35 per cent in Zambia) extrapolated to up to 17.7 million tonnes annually in 12 African countries) |
| van Loon et al. (2019) | Ghana | Severe (no exact estimate) |

**Impacts on good quality of life**

*Spodoptera frugiperda* caused crop yield loss in invaded systems and has consequently resulted in increased production costs, decline in farmers' income, hunger and worsened food insecurity (**Figure 4.44**). For example, Girsang et al. (2020) found that *Spodoptera frugiperda* led to 50 per cent and 71.4 per cent per cent increase in labour and pesticide costs in 2019, respectively, in North Sumatra province of Indonesia. Similarly, it is estimated that farmer's expenditure on pesticides has increased by US$195 per hectare (241 per cent) due to the *Spodoptera frugiperda* invasion in China's Yunnan province (Yang et al., 2021). Moreover, Kassie et al. (2020) found that *Spodoptera frugiperda* invasion was associated with a 25 per cent reduction in maize sales in southern Ethiopia, while Tambo et al. (2021) documented a reduction in per capita household income by 44 per cent and a 17 per cent higher likelihood of hunger in Zimbabwe due to severe levels of *Spodoptera frugiperda* infestation.

The *Spodoptera frugiperda* outbreak is also having negative impacts on the livestock sector in terms of reduced availability of livestock feed, such as stover, grains, straw and pasture land (FAO, 2018; Mayee et al., 2021). The Indian government imported 130,000 tonnes of maize in 2019 for the poultry industry as a result of a reduction in maize production (Mayee et al., 2021).

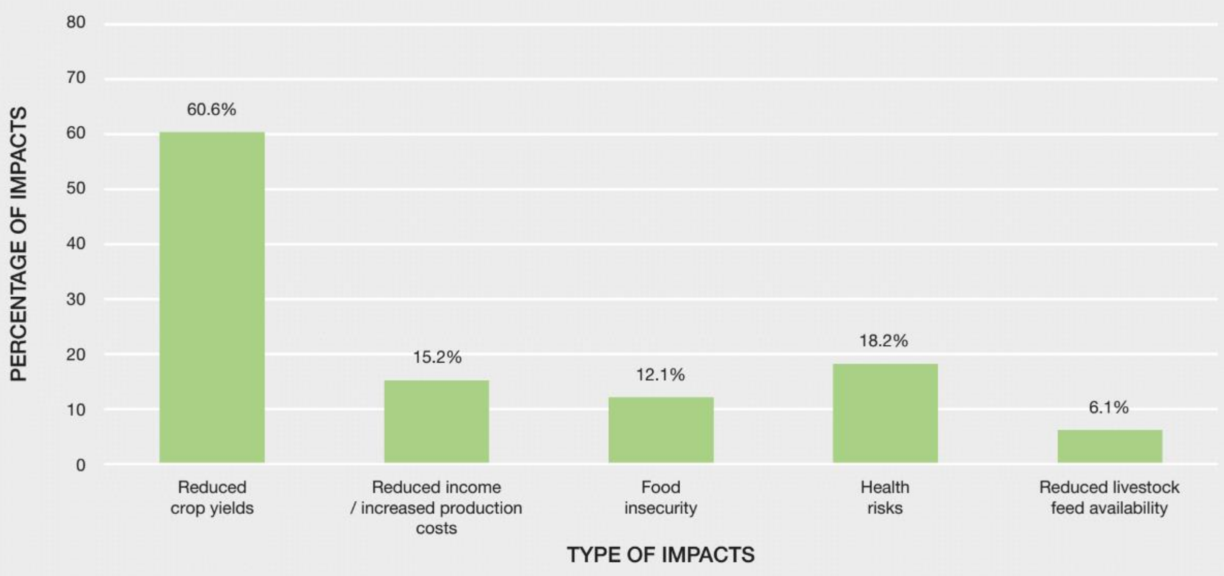


**Figure 4.44.** Percentage of documented impacts (y axis) of *Spodoptera frugiperda* (fall armyworm) on good quality of life of Indigenous Peoples and local communities. *Spodoptera frugiperda* negatively impacts crop yields, income and production costs, food security, health and livestock feed availability (x axis). The results are presented in percentages of the 33 case studies reviewed.

A data management report for the literature review underpinning this figure is available at https://doi.org/10.5281/zenodo.5760266

The synthetic pesticides used by smallholders for *Spodoptera frugiperda* control have been shown to pose high risks to human health (Murray et al., 2019, 2021; Kumela et al., 2019). Several studies have shown that farmers who used pesticide to control *Spodoptera frugiperda* experience pesticide-related illness, such as dizziness, headache, skin and eye irritation and stomach ache (Kansiime et al., 2019; Rwomushana et al., 2018; Tambo et al., 2020). The use of pesticides also has been shown to affect native species (Kumela et al., 2019).

**Positive impacts caused by invasive alien species on good quality of life in the terrestrial realm**

As with negative impacts, positive impacts in the terrestrial realm are clustered within a few units of analysis (**Table 4.27**). Cultivated areas are most positively impacted, with 79 invasive alien species causing 151 documented impacts. Tropical and subtropical dry and humid forests (70 invasive alien species causing 118 impacts) and temperate and boreal forests and woodlands (40 species causing 82 impacts) round out the top three positively impacted units of analysis. Taken together, these three units of analysis account for 75 per cent of documented terrestrial positive documented impacts. Meanwhile, the three least affected terrestrial units of analysis, Mediterranean forests, woodlands and scrub, tundra and high mountain habitats, and wetlands (peatlands, mires, bogs), account for only three per cent of positive terrestrial documented impacts.

Material and immaterial assets account for the most positively documented component of good quality of life across most units of analysis, followed by health, showing a similar pattern than for negative impacts. However, the order differs for tundra and high mountain habitats, tropical and subtropical savannas and grasslands, and temperate grasslands that are mainly impacted through positive changes to social and cultural relationships, followed by positive changes to material and immaterial assets. Safety is the least documented positively impacted component of good quality of life, accounting for only three per cent of positive terrestrial impacts.

Examining the positive impacts highlights the different ways invasive alien species interact with people across landscapes. Plants are one of the most documented taxa affecting Mediterranean forests, woodlands and scrubs (e.g., *Agave americana* (century plant)), deserts and xeric shrublands (e.g., *Prosopis juliflora* (mesquite)), and tropical and subtropical savannas and grasslands (e.g., *Acacia mearnsii* (black wattle)). This result mirrors findings from R. T. Shackleton, Shackleton, et al. (2019), who documented that most case studies on positive impacts on livelihoods involve invasive alien plants, often intentionally introduced. These plant species affect different components of good quality of life, which widely differ across units of analysis. For example, as a source of fuelwood, *Prosopis juliflora* is an important source of energy for cooking and heating, along with a possible source of income for those who sell the wood, which can cause significant positive impacts on assets. Human health is positively affected by species such as *Acacia mearnsii*, known for its antibacterial properties and effectiveness in treating illnesses as shigellosis (Olajuyigbe & Afolayan, 2012). Sociocultural relationships benefit from species such as *Agave americana* (century plant).

Tropical and subtropical dry and humid forests, temperate and boreal forests and woodlands, urban/semi-urban, cultivated areas, and wetlands (peatlands, mires, bogs), are mainly positively impacted by animals. Many of these species impact good quality of life either through material and immaterial assets, by providing a new way of creating or enhancing livelihood or through improvements to human health outcomes. *Equus ferus* (wild horse) in temperate and boreal forests and woodlands (and tundra and high mountain habitats) illustrates the prominent role some invasive alien species play in maintaining cultural identities, especially among Indigenous peoples and local communities (Bhattacharyya et al., 2011; Bhattacharyya & Larson, 2014). The remaining units of analysis, tundra and high mountain habitats, temperate grasslands, benefit from a several invasive alien plants and animals. Importantly, there are no documented cases of microbes producing positive terrestrial impacts on good quality of life.

**Table 4.27.** Positive impacts on good quality of life in the terrestrial realm

Darker colours indicate higher documented numbers of invasive alien species or impacts. A data management report for the database of impacts developed through this chapter is available at [https://doi.org/10.5281/zenodo.5766069](https://doi.org/10.5281/zenodo.5766069)

| | Material and immaterial assets | | Freedom of choice and action | | Health | | Social and cultural relationships | | Safety | |
|---|---|---|---|---|---|---|---|---|---|---|
| Unit of analysis | species | impacts | species | impacts | species | impacts | species | impacts | species | impacts |
| Tropical and subtropical dry and humid forests | 25 | 48 | 1 | 1 | 30 | 41 | 13 | 27 | 1 | 1 |
| Temperate and boreal forests and woodlands | 8 | 33 | 1 | 1 | 14 | 14 | 16 | 26 | 1 | 8 |
| Mediterranean forests, woodlands and scrub | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 |
| Tundra and High Mountain habitats | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 4 | 0 | 0 |
| Tropical and subtropical savannas and grasslands | 3 | 3 | 0 | 0 | 4 | 4 | 3 | 4 | 1 | 1 |
| Temperate Grasslands | 4 | 15 | 0 | 0 | 15 | 15 | 15 | 18 | 1 | 1 |
| Deserts and xeric shrublands | 3 | 9 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 2 |
| Wetlands – peatlands, mires, bogs | 1 | 1 | 0 | 0 | 3 | 5 | 2 | 2 | 0 | 0 |
| Urban/Semi-urban | 9 | 20 | 0 | 0 | 6 | 7 | 2 | 4 | 1 | 1 |
| Cultivated areas (incl. cropping, intensive livestock farming etc.) | 27 | 65 | 1 | 1 | 36 | 54 | 14 | 30 | 1 | 1 |

### 4.5.2.2. Patterns of negative and positive impacts of invasive alien species on good quality of life in the marine and inland waters realms

There are 575 documented negative impacts on good quality of life affecting the marine and inland waters realms.

**Negative impact caused by invasive alien species on good quality of life across units of analysis in the marine and inland waters realms**

Inland surface waters and water bodies are the most impaired of all aquatic units of analysis (151 invasive alien species causing 411 negative impacts), accounting for 71 per cent of all negative aquatic impacts (**Table 4.25**). The least affected unit of analysis, open ocean pelagic systems, has only one documented invasive alien species, generating three negative impacts on material and immaterial assets, which accounts for less than one per cent of negative aquatic impacts.

The top two components of good quality of life most negatively affected across all aquatic domains are material and immaterial assets, followed by health (**Table 4.28**). In shelf ecosystems (neritic, intertidal and littoral zone), health dominates followed by material and immaterial assets.

The top documented invasive alien species causing negative impacts on good quality of life in the aquatic realm are attributed solely to animals. Inland surface waters and water bodies are subject to impacts by invasive alien animals such as *Dreissena polymorpha* (zebra mussel) and *Cyprinus carpio* (common carp). For example, *Dreissena polymorpha*, which also impacts coastal areas intensively used for multiple purposes by humans, is known for its impacts on livelihoods and access to goods by clogging pipes used in water treatment plants, irrigation, and power generation stations (Elliott et al., 2005). *Cyprinus carpio* limits access to nutritious food and adequate livelihoods by quickly dominating native fish species, negatively affecting fishing and recreation opportunities (Beardmore, 2015; A. K. Singh et al., 2010). These two species highlight the numerous ways invasive alien species can negatively impact a single unit of analysis. Aquaculture areas are impacted by species such as *Oreochromis niloticus* (Nile tilapia) that negatively affect native fish and harms local fishermen's livelihoods (Ogutu-Ohwayo, 1990). Open ocean pelagic systems can be invaded by *Pterois* spp. (lionfish), which negatively affects commercially important native species (Johnston et al., 2017). Health is the most impacted component of good quality of life in shelf ecosystems, with, for instance, *Rhopilema nomadica* (nomad jellyfish), known for its venomous stings (Öztürk & İşinibilir, 2010).

**Table 4.28.** Negative impacts on good quality of life in the marine and inland waters realms

Darker colours indicate higher documented numbers of invasive alien species or impacts. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

| | Material and immaterial assets | | Freedom of choice and action | | Health | | Social and cultural relationships | | Safety | |
|---|---|---|---|---|---|---|---|---|---|---|
| Unit of analysis | species | impacts | species | impacts | species | impacts | species | impacts | species | impacts |
| Aquaculture areas | 38 | 69 | 0 | 0 | 4 | 4 | 0 | 0 | 1 | 1 |
| Inland surface waters and water bodies/freshwater | 64 | 224 | 16 | 41 | 32 | 83 | 23 | 44 | 16 | 19 |
| Shelf ecosystems (neritic and intertidal/littoral zone) | 11 | 15 | 0 | 0 | 14 | 35 | 0 | 0 | 0 | 0 |
| Open ocean pelagic systems (euphotic zone) | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Coastal areas intensively used for multiple | 16 | 20 | 0 | 0 | 5 | 10 | 4 | 6 | 1 | 1 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| purposes by humans | | | | | | | | | | |

**Positive impacts caused by invasive alien species on good quality of life across units of analysis in the marine and inland waters realm**

The aquatic realm had 117 positive documented impacts caused by 73 invasive alien species. Inland surface waters and water bodies (49 invasive alien species, causing 80 impacts) and Coastal areas intensively used for multiple purposes by humans (12 invasive alien species, causing 15 impacts) account for 81 per cent of aquatic realm positive impacts (**Table 4.29**). Open ocean pelagic systems are the least impacted unit of analysis, with only one documented invasive alien species, *Pterois* spp. (lionfish). Material and immaterial assets, social/cultural relationships, and health are documented to be the most affected components of good quality of life. Impacts on safety are the least documented component, and only observed in inland surface waters and water bodies where, for instance, *Pontederia crassipes* (water hyacinth) assist with creating resilient communities by removing heavy and toxic metals from waterways (Dixit & Dhote, 2010).

While invasive alien plants are documented to cause more positive impacts than negative impacts (R. T. Shackleton, Shackleton, et al., 2019), positive impacts are mostly caused by invasive alien animals in inland surface waters and water bodies/freshwater (e.g., *Oreochromis niloticus* (Nile tilapia)), in coastal areas intensively used for multiple purposes by people (e.g., *Corbicula fluminea* (Asian clam)), and in open ocean pelagic systems (e.g., *Pterois* spp. (lionfish)). Many of these positive impacts are due to changes in material and immaterial assets, such as creating new opportunities for income and recreation. Postive impacts on good quality of life in aquaculture and shelf ecosystems are mostly caused by invasive alien plants and animals. As with positive terrestrial impacts, there are no documented microbes causing positive impacts on good quality of life in the aquatic realm.

**Table 4.29.** Positive impacts on good quality of life in the marine and inland waters realms

Darker colours indicate higher documented numbers of invasive alien species or impacts. A data management report for the database of impacts developed through this chapter is available at https://doi.org/10.5281/zenodo.5766069

| | Material and immaterial assets | | Freedom of choice and action | | Health | | Social and cultural relationships | | Safety | |
|---|---|---|---|---|---|---|---|---|---|---|
| Unit of analysis | species | impacts | species | impacts | species | impacts | species | impacts | species | impacts |
| Aquaculture areas | 5 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Inland surface waters and water bodies/freshwater | 32 | 59 | 1 | 1 | 6 | 10 | 7 | 7 | 3 | 3 |
| Shelf ecosystems (neritic and intertidal/littoral zone) | 5 | 13 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Open ocean pelagic systems (euphotic zone) | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Coastal areas intensively used for multiple purposes by humans | 6 | 8 | 0 | 0 | 0 | 0 | 6 | 7 | 0 | 0 |

### 4.5.3. Documented impacts on good quality of life by taxonomic group and region

#### 4.5.3.1. General patterns

Invasive alien species affect good quality of life in all regions. Several patterns of documented impacts emerge when examining the positive and negative impacts across regions. In particular, for both negative and positive impacts, the Asia-Pacific region has the most documented impacts, followed by Europe and Central Asia, the Americas, Africa, and Antarctica. The database of impacts developed through this chapter mirrors previous reports, showing that most impacts of invasive alien species on livelihoods are documented in the developing world, particularly southeast Asia (R. T. Shackleton, Shackleton, et al., 2019). Negative impacts on good quality of life are mostly documented for material and immaterial assets and health. Safety is the least documented component of good quality of life. This result differs for positive impacts, where material and immaterial assets and social and cultural relationships are the most impacted components of good quality of life, while freedom of choice and action is least affected.

However, there are few consistent patterns when comparing the taxa that cause impacts across regions. For example, even though invertebrates cause the majority of negative impacts for most regions, the second, third, and fourth most prominent species vary for each region. The order of impacts by region is as follows, Africa: invertebrates, plants, vertebrates, microbes; Europe and Central Asia: invertebrates, microbes, plants, vertebrates; Americas: invertebrates, vertebrates, plants, microbes; Asia-Pacific: invertebrates, plants, vertebrates, microbes; Antarctica: vertebrate only. In terms of positive impacts, plants generally have the most significant number of impacts documented for all regions, except for the Asia-Pacific region, where invertebrates have the highest number of invasive alien species with documented positive impacts. Finally, negative impacts tend to be more evenly distributed across regions when looking beyond the most impacted taxonomic group (i.e., the second, third or fourth most dominant taxonomic group). In contrast, positive impacts vary widely among taxa. This result follows (R. T. Shackleton, Shackleton, et al., 2019), where the positive impacts of invasive alien species varied substantially between case studies and different species.

#### 4.5.3.2. Patterns of negative impacts on good quality of life by taxonomic group and region

A total of 484 documented invasive alien species have caused negative impacts on good quality of life in Asia-Pacific, 347 in Europe and Central Asia, 296 in the Americas, 90 in Africa, and one in Antarctica (**Figure 4.45**). Across almost all regions, change to material and immaterial assets is the most frequently documented negative impact on good quality of life. The highest number of documented negative impacts is found in Asia-Pacific (853 impacts), followed by Europe and Central Asia (598 impacts), Africa (286 impacts), and the Americas (265 impacts) (**Figure 4.46**). Antarctica only has one documented impact on good quality of life, through health changes. Health impacts are the second most commonly documented impact on good quality of life for all other regions, with the highest number of impacts documented in Asia-Pacific (290 impacts). There are 223 documented negative impacts on health in the Americas, 139 in Europe and Central Asia, and 69 in Africa. Social and cultural relationships, such as environmental equity and social infrastructure, is the third most impacted component of good quality of life, which is relatively evenly distributed across Asia-Pacific (89 impacts), the Americas (81 impacts), and Europe and Central Asia (62 impacts). Impacts on safety, such as risks to personal safety and security from disasters, have been less documented, where the top two impacted regions are the Americas (42 impacts) and Asia-Pacific (27 impacts).

The number of documented negative impacts on good quality of life for specific taxa varies by region, but some patterns do emerge (**Figures 4.45** and **4.46**). Invasive alien invertebrates are the main taxonomic group causing negative impacts on good quality of life across regions, with 594 species (51 per cent of all invasive alien species causing negative impacts on good quality of life). Negative impacts caused by invertebrates are relatively evenly distributed across regions: they have caused 494 negative impacts (31 per cent) in Europe and Central Asia, 457 in the Asia-Pacific region (30 per cent), 365 in the Americas (23 per cent), 258 in Africa (16 per cent), and none in Antarctica. Plants account for 21 per cent of all negative impacts across regions and are the second most documented taxonomic group affecting good quality of life in Asia-Pacific and Africa. More than half of negative impacts caused by plants on good quality of life are heavily concentrated in Asia-Pacific (391 impacts; 58 per cent of all impacts caused by plants on good quality of life). The remaining share of negative impacts are spread evenly across Europe and Central Asia (108 impacts; 16 per cent), the Americas (92 impacts; 14 per cent), and Africa (78 impacts; 12 per cent). There are no observed impacts of invasive alien plants in Antarctica (**Figure 4.46**). Vertebrates cause 17 per cent of documented negative impacts on good quality of life across all regions, where documented impacts are heavily concentrated in the Asia-Pacific region (347 impacts; 64 per cent of all negative impacts caused by vertebrates). There are 116 impacts (21 per cent) caused by invasive alien vertebrates on good quality of life in the Americas, 49 in Africa (9 per cent), and 30 in Europe and Central Asia (6 per cent). Vertebrates are the least documented taxonomic group in Europe and Central Asia, and there is only one impact caused by a vertebrate documented in Antarctica (**Figure 4.46**). Finally, microbes are the least documented taxonomic group to negatively impact good quality of life in most regions, accounting for 10 per cent of impacts across taxa (**Figure 4.46**).

Europe and Central Asia record the majority of impacts caused by microbes across all regions (177 impacts; 52 per cent of all impacts caused by microbes). The Americas have the second-highest share of negative impacts caused by microbes (87 impacts; 26 per cent), closely followed by the Asia-Pacific region (74 impacts; 22 per cent). There are no documented microbes affecting good quality of life in Africa or Antarctica.

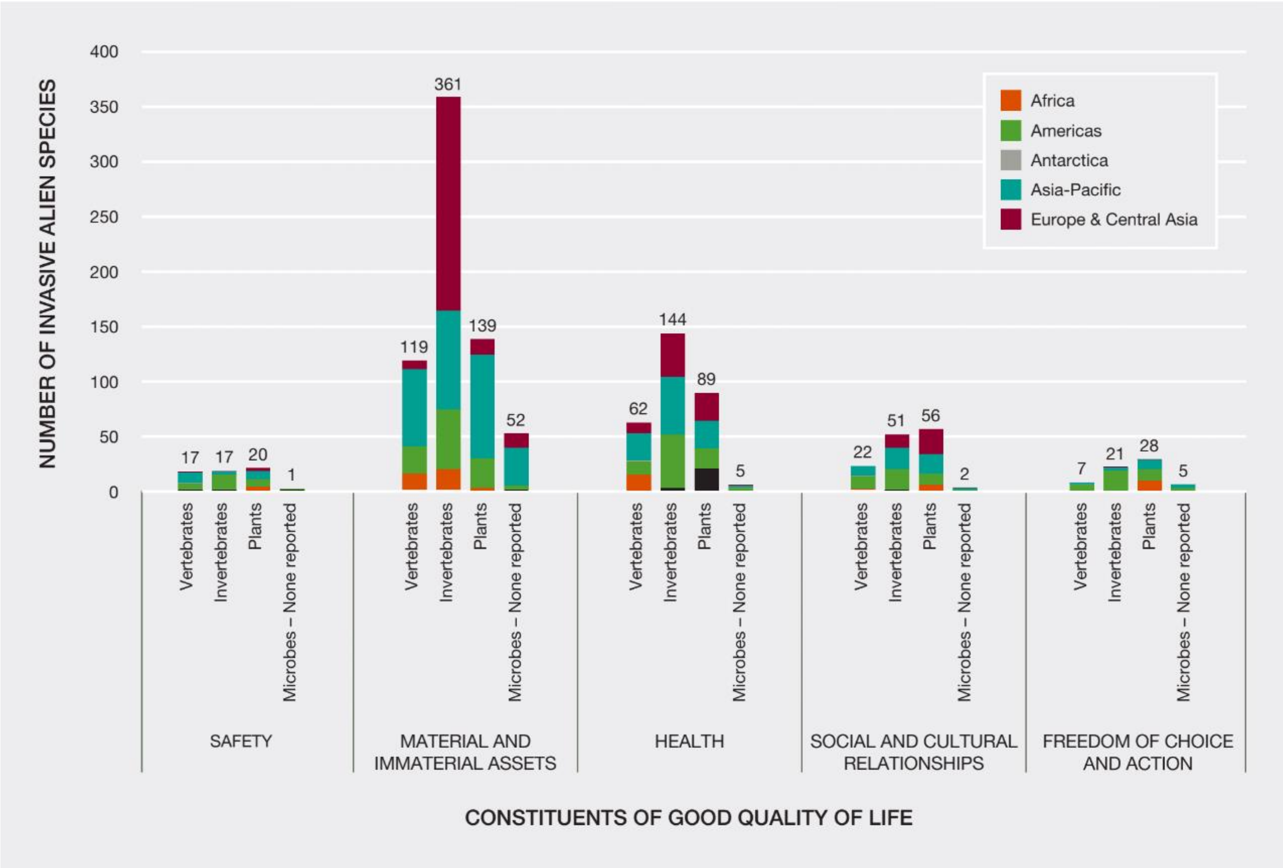


**Figure 4.45.** Number of invasive alien species (y axis) causing negative impacts on constituents of good quality of life by taxonomic group and IPBES region (x axis). A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

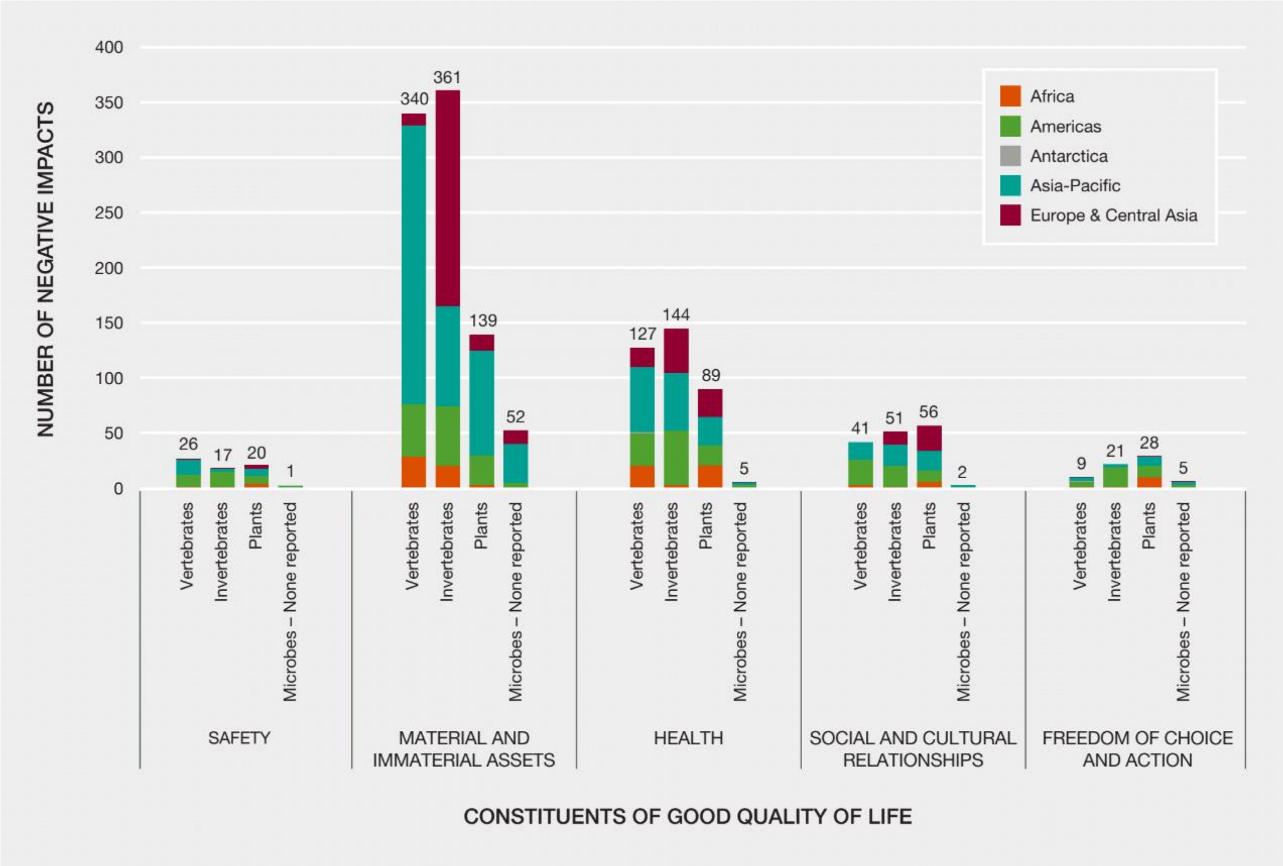


**Figure 4.46.** Number of negative impacts (y axis) on constituents of good quality of life by taxonomic group and region (x axis). A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

### 4.5.3.3. Patterns of positive impacts on good quality of life by taxonomic group and region

There are 236 documented species that cause positive impacts on good quality of life, including 156 in the Asia-Pacific region, 56 in Europe and Central Asia, 61 in the Americas, and 26 species in Africa (**Figure 4.47**). There are no documented species causing positive impacts on good quality of life in Antarctica. This pattern translates to the number of documented impacts, with 46 per cent (241 impacts) of the positive impacts on good quality of life documented in Asia-Pacific, 21.6 per cent (113 impacts) in Europe and Central Asia, 15.6 per cent (82) in the Americas, and 8.4 per cent (44) in Africa (**Figure 4.48**). Across all regions, good quality of life is mostly positively impacted through changes to material and immaterial assets (180 impacts). Health (111 impacts) is the second most positively impacted component of good quality of life across regions. There are 92 impacts on health in the Asia-Pacific region, 11 impacts in Africa, 6 impacts in Europe and Central Asia, and 2 impacts in the Americas. Social and cultural relationships is the second most impacted component to good quality of life, with 52 positive impacts in Asia-Pacific, 20 in the Americas, and 18 in Europe and Central Asia. Safety and freedom of choice and action are the two least positively impacted components of good quality of life across all regions.

Compared to negative impacts, fewer patterns emerge with positive impacts by taxonomic group and region. Plants are the dominant taxonomic group causing 37 per cent (213 impacts) of all positive impacts on good quality of life across most regions, including Europe and Central Asia, the Americas, and Africa. Of all documented positive impacts caused by invasive alien plants, 40 per cent are in the Asia-Pacific region (86 impacts). The remaining share of positive impacts occur in Europe and Central Asia (71 impacts; 33 per cent), the Americas (34 impacts; 16 per cent), and Africa (22 impacts; 10 per cent).

Invertebrates are responsible for 170 positive impacts, or 29.6 per cent of all positive impacts on good quality of life across regions. Invertebrates are the dominant taxonomic group positively affecting the Asia-Pacific region (108 impacts), accounting for 64 per cent of all invertebrate impacts. Europe and Central Asia account for 24 per cent of invertebrate impacts (41 impacts). The Americas (18 impacts; 10 per cent) and Africa (3 impacts; 2 per cent) are the regions with the fewest documented positive impacts from invertebrates.

Aside from microbes that do not have any documented positive impacts (**section 4.7.2**), vertebrates are the least documented taxonomic group causing positive impacts on good quality of life, accounting for 24 per cent of impacts by taxon. As with negative impacts, positive impacts caused by vertebrates are heavily concentrated in the Asia-Pacific region (77 impacts; 61 per cent of all positive impacts caused by vertebrates). The Americas document 30 positive impacts (24 per cent), Africa records 19 impacts (15 per cent) and Europe and Central Asia document only 1 impact (1 per cent) caused by invasive alien vertebrates on good quality of life.

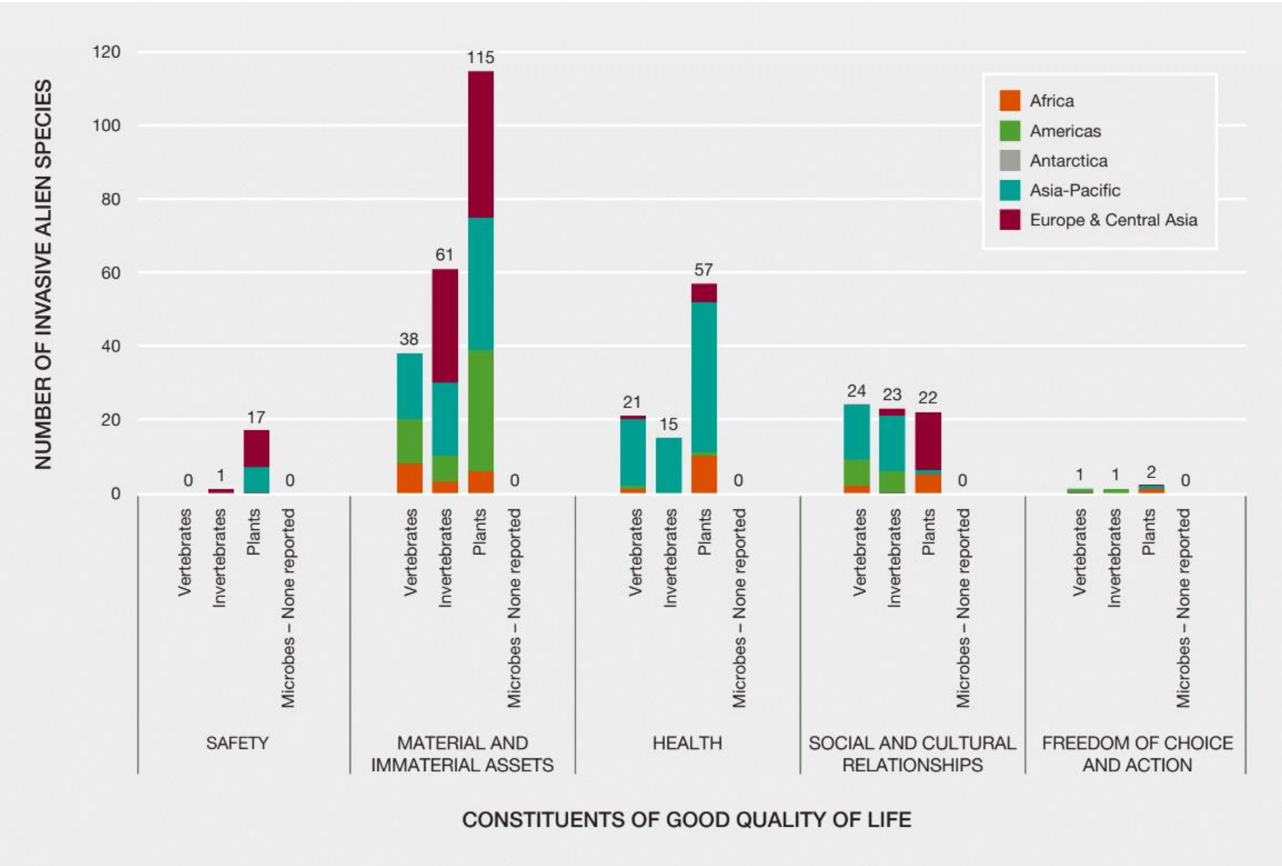


**Figure 4.47.** Number of invasive alien species (y axis) causing positive impacts on constituents of good quality of life by taxonomic group and region (x axis). A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

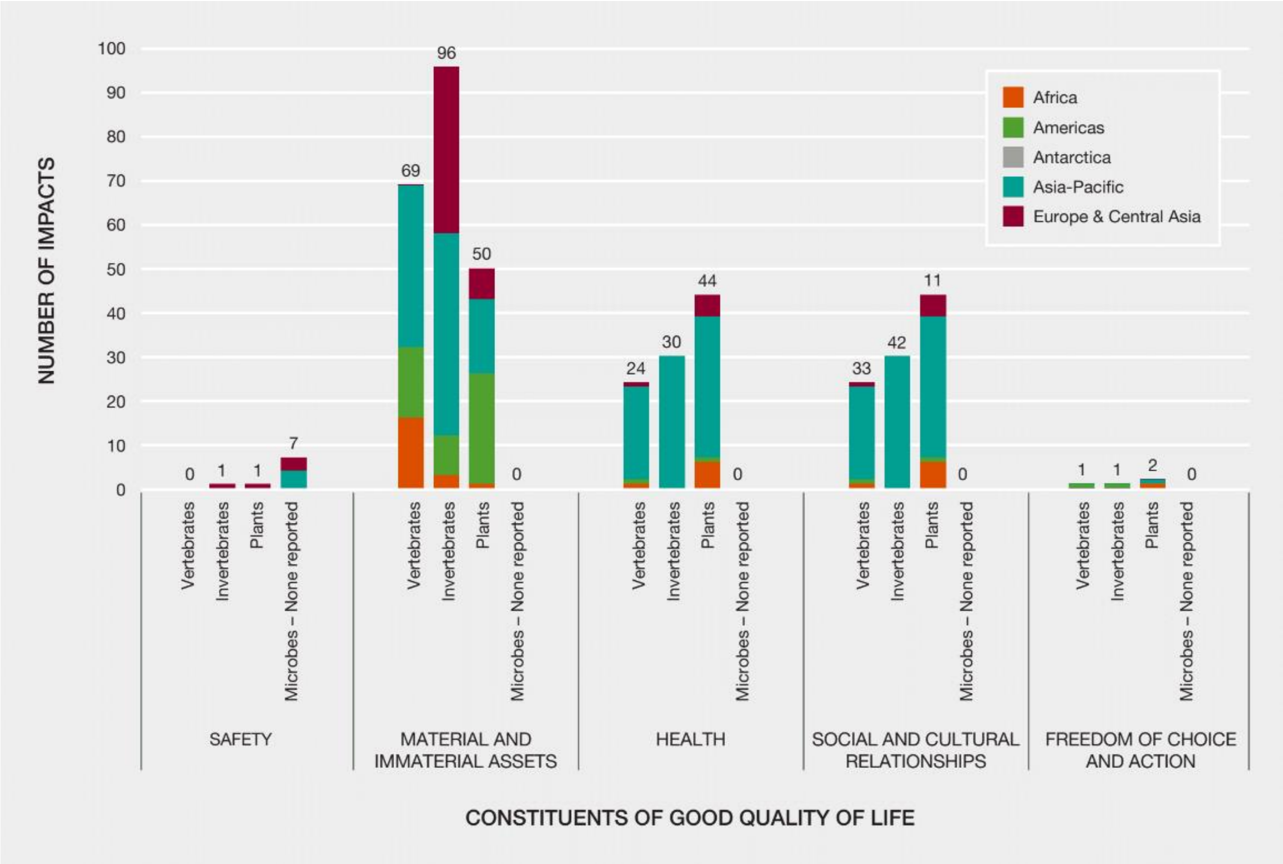


**Figure 4.48.** Number positive impacts (y axis) on constituents of good quality of life by taxonomic group and region (x axis). A data management report for the database of impacts developed through this chapter, with underlying data for this figure is available at https://doi.org/10.5281/zenodo.5766069

# 4.6. Review of impacts of invasive alien species for Indigenous Peoples and local communities

This section presents the results of a systematic cross-chapter review on Indigenous Peoples and local communities and invasive alien species,[16] which supplements the chapter impact database. Of the 131 sources reviewed, a total of 124 sources provided evidence of impacts of invasive alien species on, or as perceived by Indigenous Peoples and local communities, with 79 sources containing direct information (e.g., from survey data, interviews and quotations) from Indigenous Peoples and local communities.

Overall, this review has revealed a total of 368 impacts on nature, nature's contributions to people and good quality of life, as documented by Indigenous Peoples and local communities. Indigenous Peoples and local communities have identified a varied range of invasive alien species, with nearly two-thirds of the sources reviewed being associated with invasive alien plants. Additionally, they have documented the presence of invasive alien vertebrates and invertebrates, as well as a single microbe (**Table 4.30**). This may represent a research bias towards invasive alien plants in rural communities, but all taxonomic groups are represented in this analysis.

**Table 4.30.** The number of Indigenous and local knowledge sources reviewed with information about the impacts of invasive alien plants, vertebrates, invertebrates and microbes

A data management report for this cross-chapter literature review on Indigenous Peoples and invasive alien species is available at: https://doi.org/10.5281/zenodo.5760266

| Taxonomic group | Number and percentage of Indigenous and local knowledge sources reviewed | |
|---|---|---|
| *Plant* | 80 | 65% |
| *Invertebrate* | 14 | 11% |
| *Vertebrate* | 19 | 15% |
| *Microbe* | 1 | 1% |
| *Multiple Taxa* | 10 | 8% |
| Total | 124 | 100% |

Impacts are presented as they were described by Indigenous Peoples and local communities, but authors have assigned directions of impact following the classification used throughout this chapter (**section 4.1.2**). While it may seem straightforward to identify negative and positive impacts of alien species invasions on nature and native species (i.e., a native species suffers or is advantaged by the an invasive alien species) or on good quality of life (i.e., people derive a benefit from an invasive alien species), Indigenous Peoples and local communities have emphasized that a positive impact on nature's contribution to people or good quality of life may not be considered as wholly positive for their communities, and instead may represent the "least-worst" option (IPBES, 2022). For example, while the capture and sale invasive of alien fish species introduced into traditional fishing grounds may be considered as positive for some (Riedmiller, 1994; K. Smith et al., 2010; Cid-Aguayo et al., 2021), it may not be the case for Indigenous Peoples and local communities, especially when they have not had agency or choice in the initial introduction of the invasive alien species (K. Smith et al., 2010; Broderstad & Eythórsson, 2014), and/or if their preference still is for the native species that have been displaced (IPBES, 2022). Therefore, when interpreting the findings of this review, it is important to consider the options available to Indigenous Peoples and

[16] Data management report available at: https://doi.org/10.5281/zenodo.5760266

local communities and whether their use of and adaptation to invasive alien species has been freely determined by choice. Some Indigenous Peoples and local communities lack resources, funding and capacity to voice and implement their preferences regarding management of biological invasions, and may have chosen eradication instead of adaptation if they had access to more resources (IPBES, 2022). However, it is also important to note that some Indigenous Peoples and local communities have shown considerable capacity for adaptation using their detailed and intimate knowledge and skills connected with their environment as well as partnerships with emerging technologies, and can be a model for resilience to future impacts (**Chapter 5**, **section 5.7**, Africa Uncensored, 2022; P. L. Howard, 2019). Overall, positive impacts documented on nature's contribution to people and good quality of life refer to where humans have derived a benefit, and yet they are often part of a more complex trade-off between positive and negative impacts inherent in socio-cultural-ecological systems.

### 4.6.1. Impacts on nature as documented by Indigenous Peoples and local communities

Indigenous Peoples and local communities report that approximately 92 per cent of impacts on nature caused by invasive alien species are negative, and only 8 per cent are positive impacts (**Table 4.31**). They have observed an overall reduction in specific native species (31 per cent), and a loss in vegetation cover and diversity due to invasive alien species (19 per cent), as well as negative impacts on native animals, including displacement, reduction in animal food and habitat and predation (7 per cent combined). Indigenous Peoples and local communities note that ecosystem processes, including fire regimes and regeneration, have also been disrupted by invasive alien species (e.g., Jevon & Shackleton, 2015), and that some invasive alien species are increasing the abundance of other invasive alien species. For example, local rice farmers in Cambodia report that the invasive shrub, *Mimosa pigra* (giant sensitive plant), has increased other invasive pests such as nematodes and rodents, which are more problematic for Indigenous Peoples and local communities in their rice fields (Rijal & Cochard, 2016).

Almost one-third of the reviewed sources highlight that invasive alien species have caused the reduction in specific native animal and plant species, with impacts occurring to species of similar niche or taxon (e.g., plants outcompeting other plants) or across different taxa (e.g., plants displacing fauna). For example, the Ifugao farmers in the Philippines have noted that *Pomacea canaliculata* (golden apple snail or "batikor" in local language) outcompetes native snails (R. C. Joshi et al., 2001) and Aboriginal people in north-eastern Australia have reported that the invasion by *Rhinella marina* (cane toad) led to the disappearance of native frogs (Boll, 2006). The impact of invasive alien species on native species of a different taxon was highlighted by local communities in Nepal, who documented that the invasive vine, *Mikania micrantha* (bitter vine), limits food sources for wildlife, resulting in large and potentially dangerous fauna (tigers, rhinos, boar) increasingly leaving the forest in search of food (Sullivan et al., 2017). Indigenous Peoples and local communities value specific species that may be important to livelihoods, be totem or culturally important species, and indicator species for seasonal or environmental changes (Curran et al., 2019; C. J. Robinson & Wallington, 2012).

Aside from specific species and ecological properties, Indigenous Peoples and local communities also report an overall negative impact on biodiversity (8 per cent of reports; **Table 4.31**) which reflects their understanding of the impacts on nature as a whole. Invasive alien species causing declines in biodiversity are seen as a degradation of the overall habitat (Sundaram et al., 2012), or a reduction in the condition of the forest (Jevon & Shackleton, 2015), leading to a decline in the health of landscapes. For example, weeds have caused "significant upheaval to their Aboriginal ancestral landscapes" (Bach et al., 2019).

**Table 4.31.** Number and type of impacts on nature caused by invasive alien species, as documented directly by Indigenous Peoples and local communities

A data management report for the systematic cross-chapter review on Indigenous Peoples and local communities and invasive alien species is available at https://doi.org/10.5281/zenodo.5760266

| **Types of negative and positive impacts of invasive alien species on nature, as documented by Indigenous Peoples and local communities** | **Number of reports** | **Percentage of total reports** |
|---|---|---|
| *Total negative reports* | *57* | *92%* |
| Reduced specific species | 19 | 31% |
| Reduced vegetation diversity/abundance | 12 | 19% |
| Limits regeneration | 5 | 8% |
| Negative impact on biodiversity | 4 | 6% |
| Altered fire regimes | 3 | 5% |
| Physical damage to habitat | 3 | 5% |
| Increased abundance of other invasive alien species | 3 | 5% |
| Kills trees | 3 | 5% |
| Displaces animals | 2 | 3% |
| Kills fish | 1 | 2% |
| Predation | 1 | 2% |
| Reduced animal habitat/food | 1 | 2% |
| *Total positive reports* | *5* | *8%* |
| Provided animal habitat/food | 2 | 3% |
| Increased animals | 1 | 2% |
| Assist regeneration by limiting grazing | 1 | 2% |
| Increased vegetation abundance | 1 | 2% |

Positive impacts of invasive alien species on nature represent less than 10 per cent of impacts reported by Indigenous Peoples and local communities. Most of the reported positive impacts concern the increases in vegetation structure and cover provided by larger invasive alien shrubs and trees (**Table 4.31**). For example, in open grasslands or previously degraded landscapes, some invasive alien species have provided habitat structure or additional food for animals (Bach et al., 2019), or assisted regeneration of native seedlings underneath spiky canopies as seedlings were protected from browsing by animals (R. T. Shackleton et al., 2017).

Brazil provides an example of how Indigenous Peoples and local communities can experience a range of impacts on nature, including connections with different taxa and with ecosystem properties such as water regulation.

> *"*We live on an island surrounded by [invasive alien] acacia plants! Before, we hunted and fished, now we have bees that attack us and acacia plants that invade our farm plots as soon as we clear (burn) them, and they grow even stronger. I've killed rattlesnakes there that are attracted by the rats, and there have been more foxes and opossums, which damage the buriti palms. There are no more electric eels, and the water is rusty. You can't drink the water in the Manoá igarapé, and even our wells are drying up. The ingá trees have stopped producing fruit since the acacia appeared. Parrots used to make nests in São Domingo, but now the bees have taken over. Rolinha doves used to wake us up and tell us when it was going to rain; now those birds don't exist here anymore*"* (Souza et al., 2018, p. 6)

## 4.6.2. Impacts on nature's contributions to people as documented by Indigenous Peoples and local communities

Of the 368 documented impacts of invasive alien species,[17] over 50 per cent are on nature's contributions to people, which reflects the direct connection and dependence of many Indigenous Peoples and local communities on nature's contributions to people for their livelihoods (R. T. Shackleton, Shackleton, et al., 2019) and reveals they have valuable knowledge on more complex ecosystem processes and services (F. Walsh et al., 2013; Ens, Pert, et al., 2015). Traditional and customary practices have often been developed over a long period of time to respectfully derive services from nature (Sangha et al., 2018). Although the number of documented impacts on nature's contributions to people were relatively balanced between negative (55 per cent) and positive (45 per cent) (**Table 4.32**), the incidence of these impacts varied across categories. There are more negative than positive documented impacts on the provision of food and feed, on the availability and quality of water, and on cultural identities; whereas Indigenous Peoples and local communities report more positive than negative impacts on materials, labour and transport, energy, medicines, soil processes, physical and psychological experiences, and climate, with the last two categories mostly related to the provision of shade and ornamental aesthetics from plants (**Table 4.32**).

For Indigenous Peoples and local communities, the provision of food and feed is the most negatively impacted (31 per cent) category of nature's contributions to people (**Table 4.32Table 4.32**). This broad category includes the abundance and condition of wild food or crops for people, wild food and fodder for domestic animals and wildlife, as well as broader scale impacts such as a reduction in the size of land or interaction with other invasive alien species that cause crop damage. Impacts upon crops alone lead to various impacts on good quality of life, as local swidden farmers in West Africa documented in interviews that:

> "in decreasing order of importance, [*Imperata cylindrica* (cogon grass)], reduces crop yield, limits field size that family labour can handle, increases labour requirements for weeding, causes physical injury to the skin, reduces quality of tuber crops, increases the occurrence of bush fires in perennial crops, and increases the incidence of insects and pathogens of economic crops" (Chikoye et al., 2000; Table 4, p. 485).

Many Indigenous Peoples and local communities highlighted the negative impact of invasive alien species on livestock health (7 per cent of reports), as a specific element within food and feed (**Table 4.32**). These negative impacts subsequently affected their good quality of life, as poorer condition livestock need more labour to be looked after, and livestock have inherent cultural value. For example, Puri (2015) described how for local people from southern Karnataka, India, cattle are a cultural keystone species, and yet "Lantana camara [lantana] causes difficulties feeding cattle as it covers up and suppresses fodder grasses. This has led to underfed and malnourished animals, which has weakened them and led to increased vulnerability to disease, injury due to accidents, and attack by wild animals, such as leopards. People in these communities fear for their own safety - having to take cattle further into the forest, on to steeper and more marginal terrain, and having to stay longer every day." (Puri, 2015, p. 259).

Indigenous Peoples and local communities have reported significant impacts of invasive alien species on water resources, including water availability and security (5 per cent of reports) and water quality (3 per cent of reports). Their level of concern about these impacts was as high as that for impacts on livestock health (**Table 4.32**). Indigenous Peoples and local communities have also documented negative impacts of invasive alien species on soils (4 per cent of reports), which

[17] Data management report available at https://doi.org/10.5281/zenodo.5760266

include impacts on soil fertility, erosion, microbiological processes, and overall land degradation. In a similar holistic perspective to impacts on nature, Indigenous Peoples and local communities view soil health as connected to other ecosystem processes such as regulation of water and the provision of food and feed, health, and the land (Koichi et al., 2012).

**Table 4.32.** Number and type of impacts on nature's contributions to people caused by invasive alien species that were documented directly by Indigenous Peoples and local communities in peer-reviewed sources

A data management report for the systematic cross-chapter review on Indigenous Peoples and local communities and invasive alien species is available at https://doi.org/10.5281/zenodo.5760266

| **Types of negative and positive impacts of invasive alien species on nature's contributions to people, as documented by Indigenous Peoples and local communities** | **Number of reports** | **Percentage of total reports** |
|---|---|---|
| *Total negative reports by category* | *103* | *55%* |
| Food and feed (includes 13 reports (7%) of impacts on livestock health) | 57 | 31% |
| Freshwater quantity | 10 | 5% |
| Materials, companionship, labour | 8 | 4% |
| Soils | 7 | 4% |
| Supporting identities | 6 | 3% |
| Freshwater quality | 5 | 3% |
| Detrimental processes | 2 | 1% |
| Maintenance of options | 2 | 1% |
| Climate | 1 | 1% |
| Energy | 1 | 1% |
| Hazards | 1 | 1% |
| Medicinal | 1 | 1% |
| Physical/psychological experiences | 1 | 1% |
| Pollination | 1 | 1% |
| *Total positive reports by category* | *84* | *45%* |
| Food and Feed | 22 | 12% |
| Energy | 14 | 7% |
| Materials, companionship, labour | 12 | 6% |
| Soils | 11 | 6% |
| Medicinal | 10 | 5% |
| Physical/psychological experiences | 4 | 2% |
| Climate - shade | 4 | 2% |
| Supporting identities | 2 | 1% |
| Water quantity | 2 | 1% |
| Air quality | 1 | 1% |
| Habitat creation/maintenance | 1 | 1% |
| Hazards | 1 | 1% |

Indigenous Peoples and local communities have documented positive impacts of invasive alien species across multiple categories of nature's contributions to people, mostly on food and feed (12 per cent of reports), followed by energy (7 per cent), materials (6 per cent), soil processes (6 per cent), medicinal purposes (5 per cent), and physical/psychological experiences (2 per cent) and climate regulation (2 per cent), mostly related to shade and aesthetics from invasive trees (**Table 4.32**). Positive impacts can generally be observed by Indigenous Peoples and local communities in two situations: where invasive alien species are introduced, recognized and used for a particular purpose, and where they have adapted to the invasive alien species in a way that is different or supplementary to the original purpose of introduction or unintentional introductions. Indigenous Peoples and local communities have however highlighted that the use of or adaptation to an invasive alien species may not always be their preferred option, while other Indigenous Peoples and local communities have shown capacity for adaptation (**section 4.6**).

There are many examples where Indigenous Peoples and local communities can derive food, energy, materials and recognize land rehabilitation from invasive alien species, in line with the original purpose of introduction. Invasive alien fish species including *Oncorhynchus tshawytscha* (Chinook salmon), *Lates niloticus* (Nile perch), *Cyprinus carpio* (common carp), and *Tilapia* species have been introduced to traditional waterways as a food resource, and several Indigenous Peoples and local communities use the invasive alien species in this way to sustain their livelihoods (Riedmiller, 1994; K. Smith et al., 2010; Cid-Aguayo et al., 2021). However, Indigenous Peoples and local communities are often not the agency in charge of such introductions (K. Smith et al., 2010; Broderstad & Eythórsson, 2014), and, alongside use of the invasive alien species, they report negative impacts on the original food supply, such as native fish in this case (Macnaughton et al., 2015; Santos & Nóbrega Alves, 2016; Cid-Aguayo et al., 2021). Similarly, many invasive trees have been introduced for timber supply (e.g., *Acacia mearnsii* (black wattle)), as a fuel source for household energy (e.g., *Prosopis juliflora* (mesquite)), and for erosion control and land rehabilitation (e.g., *Grevillea banksii* (Banks' grevillea), *Prosopis juliflora*), and these species are used and recognized by Indigenous Peoples and local communities for these particular purposes (Duenn et al., 2017; Kull et al., 2019; C. M. Shackleton et al., 2007). However, Indigenous Peoples and local communities report that whilst invasive alien species are used for these purposes, the materials or energy source may be of lower quality to the original native species that they have replaced (Kull et al., 2019).

More commonly, Indigenous Peoples and local communities documented positive impacts where they adapted to the invasive alien species in new ways with additional or supplementary uses. For example, *Grevillea banksii* (Banks' grevillea) was introduced to Madagascar for erosion control but Indigenous Peoples and local communities now value this plant for honey production, as well as for charcoal and fuel, fencing, and as habitat for birds (Kull et al., 2019). Branches of the invasive shrub, *Lantana camara* (lantana), are now used to make baskets for transporting goods, and supports basketry industry for local communities in southern India (Kannan et al., 2014). Other adaptive uses for invasive alien plants include making manures and fertilizer, soaps, oils and glues, and in particular, adapting to use invasive alien plants as medicines (5 per cent of reports). Adaptation can lead to improvements in good quality of life, such as facilitating cultural knowledge transfer.

### 4.6.3. Impacts on good quality of life of Indigenous Peoples and local communities

Indigenous Peoples and local communities also experience impacts of invasive alien species on their good quality of life.[18] The systematic cross-chapter review on Indigenous Peoples and local communities and invasive alien species highlights that over two-thirds of impacts on their good

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[18] Data management report available at: https://doi.org/10.5281/zenodo.5760266

quality of life are negative (68 per cent), and less than one-third are positive (32 per cent) (**Table 4.33**).

### 4.6.3.1. Affected constituents of good quality of life

When considering the different constituents of good quality of life (**Chapter 1**, **Table 1.4**; **section 4.1.2**; **Box 4.3)**, Indigenous Peoples and local communities are experiencing both negative and positive impacts on material and immaterial assets, in a similar proportion, with 28 per cent and 24 per cent of all reports, respectively (**Table 4.33**). However, when considering all the remaining elements of good quality of life, there are far more documented negative impacts than positive impacts of invasive alien species on human health (13 per cent negative, 1 per cent positive), safety (10 per cent negative, 1 per cent positive), and freedom of choice and action (8 per cent negative, no positive reports), and slightly more negative than positive reports for social, cultural and spiritual relationships (10 per cent negative and 7 per cent positive). Spiritual impacts may have been under-documented as, for many Indigenous Peoples and local communities, spirituality is a foundational consideration for all aspects of daily living and worldview, that is interconnected with more than one constituent of good quality of life (Robin et al., 2022). However, spirituality may be private knowledge that is not shared in public research, or may be all encompassing and taken as an obvious component of everyday life that is therefore not singled out during interview questions (IPBES, 2022).

**Table 4.33.** Number of impacts of invasive alien species on the five constituents of good quality of life for Indigenous Peoples and local communities

A data management report for the systematic cross-chapter review on Indigenous Peoples and local communities and invasive alien species is available at https://doi.org/10.5281/zenodo.5760266

| Negative and positive impacts on the five constituents of good quality of life Indigenous Peoples and local communities | Number of reports | **Percentage of total reports** |
|---|---|---|
| *Total negative reports* | 81 | 68% |
| Material/Immaterial assets | 33 | 28% |
| Health | 15 | 13% |
| Safety | 12 | 10% |
| Social/Spiritual/Cultural | 12 | 10% |
| Freedom of choice/action | 9 | 8% |
| *Total positive reports* | 38 | 32% |
| Material/Immaterial assets | 28 | 24% |
| Social/Spiritual/Cultural | 8 | 7% |
| Health | 1 | 1% |
| Safety | 1 | 1% |
| **Grand Total** | **119** | |

### 4.6.3.2. Themes directly documented from Indigenous Peoples and local communities

Indigenous Peoples and local communities have consistently identified themes within the literature that reviews how invasive alien species impact the five main constituents of their good quality of life (**Table 4.34**). Some of these themes feed into multiple constituents of good quality of life, for example, maintaining access and mobility is considered by Indigenous Peoples and local communities in access to resources (material/immaterial assets, Adams et al., 2018; Kent &

Dorward, 2015), cultural sites (social/spiritual/cultural relationships; C. M. Shackleton et al., 2007; Bach et al., 2019) and the freedom to move as they have always done (freedom of choice or action, (Rettberg, 2010). This accounts for slightly different numbers of reports in **Table 4.33Table 4.33**, compared to **Table 4.34**.

**Table 4.34.** Impacts on good quality of life documented by Indigenous Peoples across different themes

Number and type of impacts on the good quality of life of Indigenous Peoples and local communities, by themes directly documented by Indigenous Peoples and local communities in the reviewed sources. Colours in the columns to the right indicate the constituents affected by the documented life theme. A data management report for the systematic cross-chapter review on Indigenous Peoples and local communities and invasive alien species is available at https://doi.org/10.5281/zenodo.5760266

| | | | Affected constituent of good quality of life | | | | |
|---|---|---|---|---|---|---|---|
| Impacts on good quality of life across themes | Number of reports | Percentage of total reports | Assets | Health | Safety | Relations | Freedom |
| Negative impacts | | | | | | | |
| Health | 15 | 13% | | | | | |
| Labour - more difficult/costly/time/amount | 14 | 11% | | | | | |
| Access and Mobility | 13 | 11% | | | | | |
| Cultural knowledge transfer/practices/relations/values | 9 | 7% | | | | | |
| Safety | 9 | 7% | | | | | |
| Livelihoods overall negatively impacted | 7 | 6% | | | | | |
| Abandon activities or land | 4 | 3% | | | | | |
| Damage to material assets | 4 | 3% | | | | | |
| Reduced land area | 4 | 3% | | | | | |
| Conflict individual level | 3 | 2% | | | | | |
| Damage to cultural sites | 3 | 2% | | | | | |
| Feeling disturbed by changes in environment and way of life | 3 | 2% | | | | | |
| Affected industry/economy | 2 | 2% | | | | | |
| Freedom of choice/action – considering future generations | 2 | 2% | | | | | |
| Enjoyment of areas | 1 | 1% | | | | | |
| Reduced income | 1 | 1% | | | | | |
| Increased expenditure | 1 | 1% | | | | | |
| Reduced social cohesion/quality | 1 | 1% | | | | | |
| Positive impacts | | | | | | | |
| Livelihood resource - income | 9 | 7% | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Cultural knowledge transfer/practices/relations/ values | 5 | 4% | | | | | |
| Develop an industry/employment | 4 | 3% | | | | | |
| Labour is easier | 2 | 2% | | | | | |
| Livelihood resource | 2 | 2% | | | | | |
| Health | 1 | 1% | | | | | |
| Livelihood resource - income savings | 1 | 1% | | | | | |
| Livelihoods - housing | 1 | 1% | | | | | |
| Relaxation | 1 | 1% | | | | | |

Impacts of invasive alien species on material and immaterial assets have been documented as negative and positive in similar proportions (**Table 4.33**), but breaking this down into themes from Indigenous Peoples and local communities, it appears that positive impacts derive from gaining income or developing an industry (10 per cent of reports combined), and negative impacts translate into increased labour, reduced mobility and access, and less availability of traditional lands (28 per cent of reports combined) (**Table 4.34**).

Some invasive alien species provide income streams and support Indigenous Peoples and local communities to engage in or develop an industry such as honey production, basketry, *Melaleuca* oil distilleries, sports fishing, hunting, or tourism (Kannan et al., 2014; Aigo & Ladio, 2016; Ens, Fisher, et al., 2015; Kull et al., 2019; Maldonado Andrade, 2019; Fache, 2021). In some cases, local industries supports employment that maintains cultural connections, with long-lasting and broad benefits to health and good quality of life for Indigenous Peoples and local communities (A. Wright et al., 2021). Industries based on invasive alien species can also provide a more stable income stream, such as charcoal-making, which is more reliable and as economically beneficial as rain-fed rice cultivation (Chandrasekaran & Swamy, 2016). Industries specialized on a single invasive alien species can however become a more susceptible income stream for people, and reduce the diversity of earlier income stream made before invasion, for example from a wide variety of non-timber forest products (Kannan et al., 2014). A study on *Lantana camara* (lantana) in Karnataka, India, showed little difference in household income derived from invasive alien species compared to original forest resources (Kannan et al., 2014). As noted before, while Indigenous Peoples and local communities can adapt to an invasive alien species and derived benefits, they may have preferred to maintain and protect the original native species, had this option been available (IPBES, 2022)

The positive reports of income from invasive alien species are contrasted with reports of harder labour, reduced access and mobility, abandoned traditional activities or abandoned/reduced land area (**Table 4.34**). Reduced access and mobility, and increases in labour requirements due to invasive alien species were both equally documented by Indigenous Peoples and local communities (11 per cent of reports each). Invasive alien species can indeed reduce access to traditional lands, cultural sites or access to basic resources such as to clean water by physically blocking travelling routes, limiting mobility of people and making it more time consuming to reach resources, and even leading to the thought of traditional lands being "blocked" by invasive alien species (R. T. Shackleton et al., 2017; Witt et al., 2019). There were no reports of invasive alien species improving access and mobility for Indigenous Peoples and local communities, nor increasing the size of available land, and only one mention of an invasive forb, *Chromolaena odorata* (Siam weed), which made labour easier for some local rice farmers in Laos (Roder et al., 1995). Ensuring the rights of Indigenous Peoples to maintain, use, and control their traditional lands (Article 26 of the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)) is important for Indigenous Peoples and local communities to maintain their cultural identity and self-determination as well as be able to better respond to and manage biological invasions. Loss of access and rights to traditional lands has been highlighted as a driver of the establishment and spread of invasive alien species (IPBES, 2022; **Chapter 3**, **section 3.2.5**), which facilitates further negative impacts.

Health of Indigenous Peoples and local communities has been documented to be more negatively impacted (13 per cent of reports) than positively (1 per cent) (**Table 4.34**). Negative health impacts include injury, allergies, toxicity, lack of access to clean water, but they have also been documented when the lands of Indigenous Peoples and local communities and nature were affected by invasive alien species (Sloane et al., 2019), inducing stress and sadness from working on "sick country" (Maclean et al., 2022), or feeling despair at the influence of humans in environmental change (Aigo & Ladio, 2016). Indirect impacts on health have also been documented such as from charcoal production derived from invasive alien species (Kull et al., 2019), and there may be more indirect health effects that have not yet been documented in the literature. There are multiple ways by which health of Indigenous Peoples and local communities can be affected. For example, Rogers et al. (2017) document that for traditional Afar pastoralists in Ethiopia, *Prosopis* (mesquite) has indirectly reduced the availability of milk for domestic consumption and/or market, resulting in a lack of cash resources for education and healthcare. Afar pastoralists also observed that their economic status, social health, and community well-being are negatively affected, leading to reduced capacity to adapt to change and cope with environmental risks, as well as contributing to a widespread feeling of despair and uncertainty regarding their overall quality of life (Rogers et al., 2017). Invasive alien species can also impact the safety and security of Afar pastoralists, as dense invasive alien plants can provide a hiding place for larger wildlife or criminals, causing violent conflict with Issa pastoralists over resources (Rogers et al., 2017).

**Impacts on society-wide good quality of life**

There are 66 documented examples where invasive alien species have impacted the well-being of communities and societies at a higher level (**Table 4.35**). More research with input from Indigenous Peoples and local communities is required on this topic as these society-level impacts have often been interpreted solely by authors of the publications. A vast majority (over 80 per cent) of these society-level impacts are negative, they include conflicts between groups, major changes in land use and resource tenure, and disruptions or other harms to ancestral cultural identities, laws and relationships (Amanor, 1991; Bekele et al., 2018; Pretty Paint-Small, 2013; Costanza et al., 2017; Sloane et al., 2019). Some positive impacts have also been documented, highlighting that adaptation to invasive alien species can contribute, in some cases, to maintain cultural institutions and knowledge, and language transfer between generations, especially when Indigenous Peoples and local communities still have access to their traditional lands (Maldonado Andrade, 2019; Bach et al., 2019). In some cases, invasive alien species have become part of the cultural identity of Indigenous Peoples and local communities (e.g., feral cattle in Hawaii, Fischer, 2007).

**Table 4.35.** Number and type of impacts on society-wide good quality of life for Indigenous Peoples and local communities

A data management report for the systematic cross-chapter review on Indigenous Peoples and local communities and invasive alien species is available at https://doi.org/10.5281/zenodo.5760266

| Negative and positive impacts of invasive alien species society-wide good quality of life for Indigenous Peoples and local communities | Number of reports | Percentage of total of reports |
|---|---|---|
| Total negative reports | 55 | 83% |
| Conflict | 15 | 23% |
| Cultural institutions | 11 | 17% |

| | | |
|---|---|---|
| Resource tenure | 7 | 11% |
| Settlement/land-use | 7 | 11% |
| Education/knowledge | 6 | 9% |
| Governance | 4 | 6% |
| Social stratification | 4 | 6% |
| Social security | 1 | 2% |
| Total positive reports | 11 | 17% |
| Cultural institutions | 3 | 5% |
| Education/knowledge | 2 | 3% |
| Resource tenure | 2 | 3% |
| Social stratification | 2 | 3% |
| Governance | 1 | 2% |
| Settlement / land use | 1 | 2% |
| Grand Total | 66 | |

### 4.6.4. Indigenous Peoples and local communities: comparing positive and negative impacts of invasive alien species

The lack of data on the magnitude of impacts of invasive alien species on nature, nature's contributions to people and good quality of life, as assessed by Indigenous Peoples and local communities (**section 4.7.2**), poses a challenge in comparing impacts between studies, regions or communities. The magnitude of impacts of invasive alien species may not be simply categorized as either wholly positive or negative, as there are often trade-offs to be considered. In some cases, the positive impacts may be the "least-worst" option, while still having some negative effects (IPBES, 2022). In 12 of the reviewed sources, Indigenous Peoples and local communities have conducted a comparison of the negative versus positive effects within the same study, considering these trade-offs. In 11 out of the 12 cases, invasive alien species were found to have more negative than positive impacts overall.

Particularly, Indigenous Peoples and local communities reported an equal number of negative and positive impacts on material and immaterial assets. Studies on the perspectives and experiences of Indigenous Peoples and local communities with invasive alien species have therefore sought further qualitative and contextual analysis through survey data to better understand these impacts (**Table 4.36**).

**Table 4.36.** Examples of invasive alien species with conflicting values

Sources retrieved from a systematic cross-chapter review on Indigenous Peoples and local communities and invasive alien species. Data management report available at https://doi.org/10.5281/zenodo.5760266

| Comparison of beneficial and detrimental impacts within the text | Invasive alien species |
|---|---|
| "Only 37% of respondents said that mimosa could be (and sometimes was) used as firewood; 63% saw no plant uses" (Rijal & Cochard, 2016) | *Mimosa pigra* (giant sensitive plant) |
| "A fifth (20%) of respondents reported eating *O. stricta* fruit, with the remaining 80% saying they ate it only rarely or never. Significantly, more men reported eating *O. stricta* than women … Respondents mentioned that a | *Opuntia stricta* (erect prickly pear) |

| | |
|---|---|
| lot of time and effort is needed to remove the small barbs (glochids) from the fruit and that it could only be eaten in moderation otherwise it would result in stomach 'irritation'" (R. T. Shackleton et al., 2017, p. 2433) | |
| "Some people use the plant's milky latex sap as a livestock insecticide, applying it to insects that are attached to cattle. However, this is not widely practiced because, as a number of participants explained, the sap is also a skin irritant and will burn a person if any touches exposed skin." (Luizza et al., 2016) | *Cryptostegia grandiflora* (rubber vine) |
| "Respondents reported that they have other trees superior to *S. spectabilis* in their compounds that serve as shade, flower and fence provision, and wind brakes." (Mungatana & Ahimbisibwe, 2012, p. 189) | *Senna spectabilis* (whitebark senna) |
| "Health problems include animal teeth falling out from eating too many *P. juliflora* pods, as a pastoralist suggested, 'For two months of the year, the pods are good so animals can eat something; if they eat it every two days it creates no problems, but too much makes the teeth fall'" (Duenn et al., 2017, p. 571) | *Prosopis* ssp. |
| "Some farmers say Acheampong [*Chromolaena odoratum*] is bad. But if you are strong and can cut out its roots it is not bad. Maize grows well where Acheampong has been. It has some moisture in its roots and this is good. But if you can't cut out its roots it is trouble. It will grow back very quickly and spoil your crops" (Amanor, 1991, p. 9) | *Chromolaena odorata* (Siam weed) |

### 4.6.5. Interactions between impacts and trends, drivers, management documented by Indigenous Peoples and local communities

**Interaction of invasive alien species trends and impacts**

Indigenous Peoples and local communities report changes in the impacts of invasive alien species depending on the trend in abundance over time. In this review, some impacts increased with time, whilst other impacts decreased depending on the interaction with livelihoods.[19] For example, *Paralithodes camtschaticus* (red king crab) was initially seen as a pest by the Saami fisher people in Norway, but was later viewed as a major economic resource (Broderstad & Eythórsson, 2014). In contrast, in Botswana, local people initially "embraced" *Prosopis juliflora* (mesquite), but as rates of spread increased in the 1990s, its negative impacts on livelihoods started to become a serious concern (Mosweu et al., 2013).

**Interactions of invasive alien species and other drivers of change amplify impacts for Indigenous Peoples and local communities**

Other drivers were identified by Indigenous Peoples and local communities to interact with invasive alien species and amplify impacts. Climate-related drivers, including drought, rainfall and temperature variability were documented as reducing the resilience of livestock and crops to invasive alien species and diseases (Rettberg, 2010; Upadhyay et al., 2020; Fenetahun et al., 2020). A lack of resources, such as limited access to irrigation equipment or tools in the context of increased labour demands, further put strain on Indigenous Peoples and local communities and their ability to cope with impacts of both invasive alien species and climate change (Rijal & Cochard, 2016). For some Indigenous Peoples and local communities, the introduction of invasive alien species to traditional lands and water is representative of human intervention by non-indigenous

[19] Data management report available at https://doi.org/10.5281/zenodo.5760266

people at sacred landscapes, which causes additional distress on well-being due to historical and ongoing disempowerment (Aigo & Ladio, 2016; Bach et al., 2019).

**Impacts of interactions between management of invasive alien species by Indigenous Peoples and local communities**

For Indigenous Peoples and local communities, positive impacts of invasive alien species can include opportunities for skills development, knowledge sharing and employment when managing biological invasions and controlling invasive alien species. For example, invasive weed management provided opportunities for elders to teach young Aboriginal peoples about culture, and to experiment with traditional burning regimes as a form of weed control (Bach & Larson, 2017). In North America, traditional methods to locate and harvest ash trees are being documented by Indigenous Nations in response to the spread of *Agrilus planipennis* (emerald ash borer), responsible for the death of culturally significant *Fraxinus nigra* (black ash). Family and tribal stories associated with traditional gathering areas are also being documented as part of this effort (Poland et al., 2017; Reo et al., 2017; **Box 4.14**).

Some reports have emphasized that the management of biological invasions can divert resources, such as time and money from other important priorities, or even cause harm itself. For instance, forest management committees in Nepal have been allocating a portion of their annual income for the management of *Mikania micrantha* (bitter vine), which would be otherwise spent on infrastructure development and social services (Sullivan & York, 2021). Additionally, they have reported an increase in the amount of labour and time required for controlling invasive alien species (**Table 4.34**). As mentioned in previous sections, Indigenous Peoples and local communities have also reported experiencing health problems when controlling invasive alien species, particularly through the excessive or unsafe use of pesticides (Head & Atchison, 2015; Machekano et al., 2017).

# 4.7. Discussion and future directions

## 4.7.1. Models and scenarios of impacts

Authors have conducted a systematic literature review of 778 papers on models and scenarios involving biological invasions, of which 171 papers address the impacts of invasive alien species.[20] Most studies consider the impacts of invasive alien species to native species or native ecosystems, and 18 per cent (31 papers) consider the impacts of invasive alien species on nature's contributions to people, 8 per cent (14 papers) on good quality of life, and 1.8 per cent (3 papers) on Indigenous and local knowledge (**Table 4.37**). Material contributions (assets) are the most well-studied, both in nature's contributions to people and good quality of life. Most model and scenario studies on impacts of invasive alien species are conducted in the Americas, followed by Europe and Central Asia, and Asia and the Pacific (**Table 4.38**). The United States has been the most extensively modelled country, followed by Australia, New Zealand, and Canada (**Table 4.39**). Modelling studies in Europe often include more than one country and these studies are covered under the "several" category in **Table 4.39**. Process-based models are the most frequently used (81 papers) to study the impacts of invasive alien species, followed by correlative models (68 papers), hybrids (19 papers) and expert-based system (3 papers). The largest proportion of studies used exploratory scenario (138 papers), followed by policy-screening scenario (17 papers) and target-seeking scenario (16 papers). Climate change is the largest scenario type (60 papers), followed by invasive alien species managements. The most modelled taxonomic group for impact assessment is invertebrates (63 papers), followed by plants (54 papers), mammals (23 papers), and fish (22 papers). Terrestrial realm is the most frequently modelled realm (126 papers) followed by inland waters and marine.

Models quantifying the impacts of invasive alien species can be a helpful tool to inform decision-makers and stakeholders as they evaluate management options. The systematic review showed that a large proportion of model and scenarios studies focus on predicting the potential distribution ranges of invasive alien species (61 per cent), often using climate change scenarios (48 per cent), but the efforts to evaluate their impacts on nature's contributions to people, good quality of life and Indigenous local knowledge are limited. Building such models faces numerous challenges (Venette, 2015; Leung et al., 2012) because the impacts of invasive alien species on nature, nature's contributions to people, and good quality of life are complex and highly context-dependent, and differ among invaded regions (Essl et al., 2020; Kumschick et al., 2015). Moreover, predicting future trajectories of the impacts of invasive alien species depends on the development of reliable scenarios for the introduction, time lags, and spread of the invasive alien species, but such attempts are still limited (Corrales et al., 2018; Essl et al., 2019). Currently, predicted trajectories of invasive alien species are primarily based on experts' knowledge and opinions from western regions, and inputs from other regions are rare (Essl et al., 2020). Recently, however, conceptual frameworks for building alien species scenarios are emerging (Lenzner et al., 2019), and future predictions of invasive alien species incursions and spread have been evaluated at the continental scale (Seebens et al., 2021). Those studies will help to develop scenario-based assessments, such as climate change (IPCC, 2014) or biodiversity loss (IPBES, 2016), for biological invasions in the near future. Moreover, standardized global impact assessment schemes (Bacher et al., 2018; IUCN, 2020; Vimercati et al., 2022) and databases, such as InvaCost for the economic costs of biological invasions on a global scale (Diagne, Leroy, et al., 2020), are available. A recent InvaCost study showed rising economic costs of biological invasions both in management and damage caused by invasive alien species (Diagne, Leroy, et al., 2020; Diagne, Turbelin, et al., 2021). Although there is no such global database nor study for the impacts of invasive alien species on native species or native ecosystems (but see **section 4.3.1**), it is most likely that those impacts are also increasing,

[20] Data management report available at https://doi.org/10.5281/zenodo.5706520

since the number of invasive alien species establishments is still increasing globally (Seebens et al., 2017; **Chapter 2**, **section 2.2.1**). Combining the predicted distribution of invasive alien species with those studies will provide an excellent opportunity to estimate the impacts of invasive alien species in a changing world.

The systematic literature review on scenarios and models completed for this assessment only focused on studies published in English, resulting in a potential bias towards western countries, especially English-speaking countries. Indeed, the United States is by far the most represented country in the dataset (23 per cent), followed by Australia (8 per cent), New Zealand (3 per cent) and Canada (3 per cent). Countries in other regions, especially Africa, are much less prevalent or missing altogether A recent study showed that non-English studies can contribute to improve our knowledge in conservation biology (T. Amano et al., 2021), as well as estimation of the costs of biological invasions (Angulo, Diagne, et al., 2021).

**Table 4.37.** Number of publications on the impacts of invasive alien species on nature's contributions to people, good quality of life, and Indigenous and local knowledge, using models and scenarios

Data management report available at https://doi.org/10.5281/zenodo.5706520

| | Type of impact | Both | Negative | Positive | Total |
|---|---|---|---|---|---|
| Nature's contributions to people | | | | | |
| No | | 16 | 120 | 4 | 140 |
| Yes | | 7 | 22 | 2 | 31 |
| | Material | 1 | 12 | 1 | 14 |
| | Non-material | | 3 | | 3 |
| | Regulating | 6 | 7 | 1 | 14 |
| Good quality of life | | | | | |
| No | | 22 | 129 | 6 | 157 |
| Yes | | 1 | 13 | | 14 |
| | Material | 1 | 8 | | 9 |
| | Non-material | | 5 | | 5 |
| Indigenous and local knowledge | | | | | |
| No | | 23 | 139 | 6 | 168 |
| Yes | | | 3 | | 3 |

**Table 4.38.** Number of publications per region on the impacts of invasive alien species using models and scenarios

Data management report available at https://doi.org/10.5281/zenodo.5706520

| IPBES regions | No. papers |
|---|---|
| The Americas | 73 |
| Europe and Central Asia | 41 |
| Asia and the Pacific | 30 |
| NA/NS (Not applicable/Not stated) | 10 |
| Africa; The Americas; Asia and the Pacific; Europe and Central Asia | 8 |
| Africa | 4 |
| Africa; Europe and Central Asia | 1 |
| Asia and the Pacific; The Americas | 1 |
| The Americas; Africa | 1 |

| | |
|---|---|
| The Americas; Asia and the Pacific; Africa | 1 |
| The Americas; Asia and the Pacific; Europe and Central Asia | 1 |
| Grand Total | **171** |

**Table 4.39.** Number of publications per country (top 12) on the impacts of invasive alien species using models and scenarios

**Data management report available at** https://doi.org/10.5281/zenodo.5706520

| Countries | Number papers |
|---|---|
| United States of America (the) | 54 |
| Several | 37 |
| Australia | 11 |
| New Zealand | 7 |
| Canada | 6 |
| France | 4 |
| Mexico | 4 |
| Finland | 3 |
| Germany | 3 |
| Italy | 3 |
| Japan | 3 |
| Portugal | 3 |

### 4.7.2. Challenges for future studies of impacts (based on knowledge gaps)

Chapter 4 identifies a number of challenges that may limit the understating of impacts of invasive alien species. This section highlights the main challenges that have been identified in the hope that future research will help close these important knowledge gaps. Aiming for a more complete and global understanding of the impact of invasions will contribute to their successful management and governance (Nuñez et al., 2020; **Chapters 5** and **6**).

The data and information presented in this chapter reveal substantial geographical and taxonomical gaps on the documentation, quantification and understanding of impacts, with lesser-studied regions potentially more affected, and lesser-studied taxa potentially more impactful (e.g., invasive alien viruses, bacteria, protists, fungi). The quality and quantity of impact information available for different taxa, units of analysis, regions and realms differ greatly, and research efforts for invasive alien species impacts are unevenly distributed geographically, temporally, and taxonomically.

The impact database developed through this chapter highlights the incompleteness of information on impacts of invasive alien species in Central Asia (mainly due to language barriers) and Africa. There are also discernible biases within regions. For example, in Africa, most impacts are documented from South Africa; eastern and northern Africa being much less covered.

These biases are observed across all realms, but especially in marine ecosystems, where the extent and timing of research efforts lag behind terrestrial studies (Ojaveer et al., 2015). Quantitative data on ecological impacts are generally scarce, even in well-studied regions. Although research on marine invasive alien species is relatively recent (initiated in the 1960s and 1970s), there are already distinct geographic and taxonomic knowledge biases on impacts of marine invasive alien species. Impacts for the vast majority of marine alien species have not been quantitatively or experimentally studied over sufficiently long temporal and spatial scales, and their cumulative and synergetic connections with other drivers of change affecting the marine environment are largely unknown. A literature survey on alien marine macroalgae revealed information on impacts for only

30 species globally (Davidson et al., 2015). Evidence for most of the documented ecosystem impacts in European seas is based on expert judgement or correlations, with only 13 per cent of the documented impacts inferred from manipulative or natural experiments. A similar paucity of impact data is apparent in North America. A recent synthesis of global ecological impacts[21] comprises 76 species, about 4 per cent of documented marine alien species, and the ecological impacts of 49 of the species were quantified in only one study each.

This chapter also highlights biases in the study of impacts of invasive alien species across units of analysis: in the marine realm, most studies were confined to intertidal/shallow subtidal areas, and in the terrestrial realm few impacts have been documented in deserts, tundra and high elevation mountainous habitats.

The impact database developed through this chapter also reveals a lack of understanding and synthesis of impacts of invasive alien microbes across all regions of the world. Some microbes are pathogens of plants, animals or humans, and due to their small size and parasitic lifestyle, many microbes can frequently be transported, introduced and established. While microbes can be considered as invasive alien organisms (Nuñez et al., 2020; H. E. Roy et al., 2017), they have been long ignored in the field of ecology, and this could be a reason for their small representation.

Similar to trends in publications in other disciplines (Nuñez et al., 2021), many of the publications reviewed in this chapter focus on impacts occurring in a narrow set of wealthy countries. Although references in other languages could drastically improve the understanding of impacts of invasive alien species, about 95 per cent of the publications listed in the impact databased developed through this chapter are in English, severely underrepresenting studies in non-English scientific journals (Angulo, Diagne, et al., 2021; Nuñez & Amano, 2021).

The intrusion of geopolitical boundaries in biological invasion science constitutes another information-related challenge, as invasive alien species are often transported from one region to another within the same country. Subsequently, a species native to one region may, under certain definitions, be considered invasive in another region in the same country, especially in large countries (Nelufule et al., 2022). In the impact database developed through this chapter, geopolitical boundaries have been considered, i.e., species were only defined alien if they crossed national borders.

Context dependency presents a fundamental challenge (Sapsford et al., 2020) when determining whether impacts are deemed detrimental or beneficial. Assessing the directionality of impact can be influenced by subjective human perceptions and values, resulting in potential disagreement among different stakeholders. Some invasive alien species have conflicting values associated with them, whereby they may cause negative impacts for some, but may be treasured by others. They may negatively affect some native taxa, but create conditions that favour other native taxa (Vitule et al., 2012) or have economic benefits to some sectors (**Box 4.10**). Impacts may also change over time, with some species having very low negative impacts for long periods of time, before they become highly problematic (**Chapter 1**, **section 1.4.4**; **Chapter 2**, **section 2.2.2**; Essl et al., 2012). Furthermore, the same invasive alien species can also have a large impact in one area but no impact in another (Zenni & Nuñez, 2013). A deeper understanding on the socioecological context of conflict species and time lags will contribute to more successful management programmes (**Chapter 5**, **section 5.6.1.2**).

This chapter highlights several other research and knowledge gaps that impede a comprehensive understanding of impacts of invasive alien species. Compared to the information available on impacts on nature, there is incomplete data on impacts on nature's contributions to people and good

[21] https://www.marinespecies.org/introduced/

quality of life. Furthermore, there is very little systematic research on gender differences in impacts of invasive alien species beyond anecdotal evidence of direct impacts (for further examples see IPBES, 2022). Most studies on impacts of marine invasive alien species relate to impacts on nature, including ecosystem health. The number of marine invasive alien species with sufficient data to satisfy the criteria for "significant negative impact" is small, as the understanding of marine ecosystem functions is constrained. Unless impacts are conspicuous, induce direct economic cost, or impinge on human health, they fail to elicit public awareness, attract funding, or result in scientific analysis (Katsanevakis et al., 2014; Ruiz et al., 1999). Improving the data and understanding on the extent and variety of the impacts marine invasive alien species create, singly and cumulatively, will contribute to providing timely and efficient management and policy instruments.

Finally, impacts resulting from interactions amongst invasive alien species and with other drivers of change, are largely misunderstood. Interactions among co-occurring invasive alien species ("invasional meltdown"; **Glossary**; **Chapter 1**, **section 1.3.4**; **Chapter 3**, **section 3.3.5.1**; Simberloff & Von Holle, 1999) or with other drivers of change can exacerbate their impacts and facilitate additional invasive alien species, increasing competition with native species, and creating new challenges for restoration (**Glossary**) of native habitats (Kuebbing & Nuñez, 2016). For instance, global extinctions (**Box 4.4**) are often caused by multiple factors, including invasive alien species. Understanding the interactions of invasive alien species with other drivers of change such as land- and sea-use change, climate change, pollution and sociocultural drivers (e.g., hunting of wildlife), will improve the understanding of impacts of invasive alien species and inform future predictions of the impact of invasive alien species.

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