Managing Invasive Alien Species in Forest Corridors and Stepping Stones

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Tree of heaven. (Photo: BFW/Anna-Maria Walli)

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Abstract

Invasive alien species (IAS) pose a significant threat to forest ecosystems by disrupting ecological networks and competing with native species. Forest habitat patches and corridors designed to enhance connectivity and biodiversity can unintentionally promote the dispersal of IAS, further compromising the ecological integrity of the forest ecosystem. This chapter discusses two main aspects related to IAS and forest connectivity: (1) the spread of IAS in the landscape and their impacts on native species and (2) the consequences of IAS on forest connectivity. Effective management of IAS is crucial to improve connectivity for native species while restricting the spread opportunity for aliens and preserve biodiversity. Ideally, a site-specific risk analysis should precede conservation or restoration efforts, determining the potential impact of IAS on the respective habitat patch's structural and functional connectivity, and vice versa. Furthermore, this chapter explores management strategies to control IAS, including physical removal, biological control, and monitoring. Citizen involvement and remote sensing play vital roles in supporting management actions, IAS detection and long-term monitoring, and habitat connectivity. Including stakeholders such as forest owners and managers in such actions ensures a collaborative approach to safeguarding forest ecosystems from the threats posed by IAS.

Keywords

Biological invasions · Introduction · Invasive alien species · Non-native species · Clearing · Connectivity · Fragmentation · Landscape matrix · Management · Pathway management · Prevention · Spread

Introduction

Invasive alien species (plants, fungi, microorganisms, and animals deliberately or accidentally introduced by humans, which threaten ecosystems, habitats, or species—hereinafter IAS) are significant contributors to global biodiversity loss, and

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the impacts of some IAS can cause degradation of unique habitats and entire ecosystems (Dukes and Mooney 1999; Vilà et al. 2011; Simberloff et al. 2013; Archer et al. 2018; IPBES 2023). According to the Convention on Biological Diversity (CBD) definition, the term "invasive alien species" refers to alien species whose introduction by humans and/or natural or human-assisted spread threatens biological diversity, as defined in Article 8(h) of the Convention and recalled in numerous other documents from COP 4 Decision IV/1 to COP 14 Decision 14/11. The original CBD definition was broadened, however, so that an IAS is now an alien species that not only has adverse impacts on biodiversity but may also cause economic or environmental harm or negatively affect human health. In fact, IAS can cause a wide variety of impacts: they can compete with native species for resources, disrupt food webs and plant-pollinator interaction networks, hybridise with native or alien congeneric species, cause problems through herbivory and predation of native species, and act as vectors or hosts for new pest and pathogens. In addition, they spread rapidly, thus necessitating timely management decisions (e.g. Wilson et al. 2016; De Groot et al. 2022; Langmaier and Lapin 2020; Lapin et al. 2021; Vaz et al. 2018).

Many forests around the world are continually subject to severe outbreaks of IAS, which can have massive environmental and sociocultural impacts (Roy et al. 2014). For example, mangrove forests dominated by halophytic plant communities and occurring predominantly along the tropical and subtropical coastlines offer important and unique ecosystem functions and services (Biswas et al. 2018). Many mangrove species are presently threatened with extinction, for example, due to deforestation, land-use changes, and IAS. Furthermore, the planting of fast-growing alien mangrove species has been used as a tool for mangrove restoration/reforestation in America, Australia, and Africa. However, the fast growth ability of these alien species can lead to them becoming invasive as they may potentially replace co-occurring native mangroves due to higher growth performance and phenotypic plasticity (Fazlioglu and Chen 2020). Therefore, effective management strategies for IAS should consider both preventive measures and the reduction of their potential for migration and dispersal, ultimately aiming to avoid or minimise their negative impacts (McNeely et al. 2001). Alarmed by the continuous loss of biodiversity, Target 7 of the Kunming–Montreal Global Biodiversity Framework (CBD/COP/DEC/15/4, 19 December 2022) invites parties and other governments to eliminate, reduce, and/or mitigate the impacts of IAS on biodiversity and ecosystem services by identifying and managing pathways of the introduction of alien species; preventing the introduction and establishment of priority IAS; reducing the rates of introduction and establishment of other known or potential IAS by at least 50 per cent by 2030; and eradicating or controlling IAS, especially in priority sites. In this context, it is essential to improve our knowledge of IAS in forest corridors and stepping stones—although the relationships between forest connectivity or fragmentation and IAS can be multifaceted (Table 17.1**.**) and must be assessed on a case-by-case basis. In this chapter, the term *forest corridor* is used as an equivalent to *ecological corridor* (Hilty et al. 2020), i.e. meaning a clearly defined geographical space that is governed and managed over the long term to maintain or restore effective ecological connectivity. We include in this category wildlife crossings and similar human

Table 17.1 The table summarises the results of a non-systematic literature review highlighting the multi-faced relationships among invasive alien species' (IAS) establishment and spread, native species (NS), and forest connectivity (and its complement forest fragmentation) and the two types of corridors considered in this chapter, i.e. forest corridors (ecological corridors) and artificial corridors

Relationship or interaction	Effects on IAS	Effects on NS	References
Corridors may favour the movement of IAS. For example, forest roads can facilitate the spread of IAS.	+		Simberloff et al., 1992; Mortensen et al., 2009
Small habitat patches may facilitate the presence of IAS.	+		Lawrence et al., 2018
Landscape structure may affect the spread of IAS and the invasibility of communities in several ways. It is an important predictor used in several types of models.	+/-	+/-	Chabrerie et al., 2007; With, 2002; Roy et al., 2016; Lustig et al., 2017; Fergus et al., 2023
Landscape and connectivity metrics are a spatial tool that can be used to support and guide IAS management decisions.			Todd et al., 2014; Stewart-Koster et al., 2015; Buchholtz et al., 2023;
IAS with a high probability of random long-distance dispersal can best be managed by focusing on the largest patches, while IAS with a lower probability of random long-distance dispersal can best be managed by considering landscape configuration and connectivity of the patches.			Minor & Gardner, 2011
IAS management can enhance landscape connectivity, and algorithms on its incorporation into	-	+	Glen et al., 2013

infrastructure aiming to form safe natural corridor bridges for animals to migrate between conservancies, for example, in the case of road traversed by such corridors. On the other hand, we use the term *artificial corridor* to indicate the CBD corridors pathway category (European Commission 2020), which refers to the movement of alien species into a new region following the construction of transport infrastructures in whose absence spread would not have been possible. In the framework of the present chapter, such artificial corridors include human infrastructures built in forest environments for purposes different from restoring or promoting ecological connectivity, such as canals (connecting river catchments and lakes), tunnels, bridges, roads and railways, forest roads, and land uses different from the natural forest (i.e. including plantations with non-native trees or clearcuttings for the establishment of safety corridors for electricity lines), fragmenting forests environments or mainly accidentally linking forest patches.

In general, forest habitat patches that function as ecological corridors or stepping stones may be invaded and promote the spread of IAS (Liebhold et al. 1995; Roy et al. 2014; Langmaier and Lapin 2020). This can allow IAS to endanger protected area networks—for example, outbreaks of destructive alien insect herbivores can be facilitated by connectivity among forest patches, allowing them to disrupt many ecosystem services (Kenis et al. 2009). Conversely, existing connectivity for native species within a landscape can be impeded by the presence of IAS when they limit dispersal or increase the mortality of dispersers (Glen et al. 2013). For these reasons, IAS management can enhance both landscape connectivity and nature conservation in forests. Today, almost a third of all endemic Caribbean forest-dependent bird species are threatened with extinction, largely due to habitat loss, IAS, and over-exploitation (Devenish-Nelson et al. 2019), while endemic island forest types are threatened by IAS such as the *Scalesia pedunculata* forest in the Galapagos (Riegel et al. 2023).

Yet, in specific contexts, there may also be positive effects of IAS on connectivity, as shown by the study on Madagascan lemurs in the *Mandena* littoral forest, a matrix of littoral forest, littoral swamp, and *Melaleuca* swamp habitats. Here, the alien *Melaleuca quinquenervia* has invaded the wetland ecosystem, creating a mono-dominant habitat that currently provides the only potential habitat forest corridor for lemurs between forest fragments (Eppley et al. 2015). The multifaceted relationship between IAS and connectivity has led to controversial proposals that require further careful evaluation, such as introducing *Opuntia* spp. cacti in Madagascar because hedges of these succulents may help in maintaining viable populations of several endemic species (Andriamparany et al. 2020).

This chapter aims to explore the complex interactions between IAS and forest connectivity. We will discuss how spatial patterns of IAS distribution, driven by their dispersal and influenced by the landscape structure, can directly affect the permeability of the landscape for native species. Understanding these patterns is crucial for effective management, especially when targeting individual IAS to conserve vulnerable habitats and rare native species under protection management. Moreover, we will delve into the direct consequences of IAS on the spread of native organisms and the overall connectivity of forest ecosystems. By comprehensively examining the dispersal patterns of IAS and their impacts on the spread of native species, this chapter seeks to provide valuable insights for effective IAS management in forest ecosystems. Implementing such knowledge is essential for conservation efforts, preserving biodiversity, and maintaining the ecological integrity of forested landscapes, ultimately safeguarding the essential connectivity that supports the health and resilience of forest ecosystems (see also Chap. 16).

Dispersal of IAS in the Context of Forest Connectivity and Fragmentation

The concept of landscape connectivity dates to the 1970s and 1980s and was developed under the inclusion of several key components (Fahrig et al. 2021; see also Chap. 1). Forest connectivity can also be defined as the complement to forest fragmentation (Maes et al. 2023). While forest connectivity is vital for promoting biodiversity and ecosystem functioning, it is very vulnerable when it is not robust, and maintenance of certain ecological processes may not be enabled by increases in landscape connectivity alone (Pelletier et al. 2017). The presence of IAS can impede connectivity between habitat patches for native species by discouraging dispersal through degraded stepping stones or by increasing mortality through predation (Closset-Kopp et al. 2016; Glen et al. 2013). Floodplain forests are among the most severely IAS-affected forest habitat types. In heavily affected forest areas, the influence of IAS leads to changes in species composition and structural diversity and, in extreme cases, to changes in biotic and abiotic site conditions (Dreiss et al. 2016; Langmaier and Lapin 2020).

In a recent synthesis of biological invasion hypotheses associated with the introduction–naturalisation–invasion continuum (Daly et al. 2023), all stages of the invasion process are described in detail. In a forest context, the initial stage involves the transfer of alien species from their native range to a new location. Once introduced, the alien species can establish itself in the new forest environment. This stage involves the species surviving and reproducing with a self-sustaining population in the new location and adapting to the new biotic and abiotic conditions. Once established, the alien species may spread and occupy new forest areas, becoming invasive. Typically, an IAS spreads rapidly to new areas, either through natural dispersal mechanisms such as anemochory, zoochory, or hydrochory or through human activity such as land-use changes, trade, timber transport, or harvesting operations, and artificial corridors are common pathways for spread. This often leads to negative impacts on the invaded native ecosystem. The spread of an alien species can be described as an expansion phase in which the range or invaded area occupied by the species increases over time. Besides stochasticity, the spread is dependent on several biotic and abiotic factors such as a species' reproductive success, localised dispersal of propagules, long-distance dispersal aided by humans and landscape permeability (O'Reilly-Nugent et al. 2016), and carbon dynamics (Fridley et al. 2023). Several stages of the dispersal of alien species have been identified (Blackburn et al. 2011; Wilson et al. 2016), with some peculiarities for specific groups such as alien forest pathogens (Paap et al. 2022). IAS spread differs at various scales (Pyšek et al. 2008), and different species have different dispersal abilities (Zhou et al. 2021).

As mentioned in the introduction of this chapter, forest connectivity (and its complement, forest fragmentation) can both promote or constrain the dispersal of IAS within forests. A summary from a non-systematic literature review of such double-fold effect is reported in Table 17.1. Enhancing connectivity—for example, by establishing forest habitat patches and natural forest corridors—is a common conservation or restoration strategy aimed at maintaining species dispersal and increasing the diversity of native populations (Pirnat 2000; Hilty et al. 2020). At the same time, the presence of both forest corridors and artificial (human-made) corridors can also be one of the most important factors in facilitating the dispersal of IAS (Blackburn et al. 2011, Closset-Kopp et al. 2016). For example, roads, water channels, and electricity and gas lines can easily promote the dispersal of IAS through forests (Deeley and Petrovskaya 2022; Dalu et al. 2023). This is generally the result of multiple processes and factors—for example, the openness of such human-made areas, the disturbance they cause, or accidental transport by people via hitchhiking or bringing in contaminated soil. Forest roads contribute to forest fragmentation and can increase the openness of forests, thereby creating pathways for more light-demanding IAS. For example, studying the invasion of *Ailanthus altissima* in the Fontainebleau Forest, a peri-urban forest of Paris (France), Motard et al. (2011) concluded that *A. altissima* grows best in edge habitats or disturbed sites—i.e. along the edge of roads, railways, gardens, meadows, and riverbanks. From these preferred locations, it can spread through the underwood, where light is not a limiting factor. They also concluded that the *A. altissima* plants detected within the forest stands represented individuals favoured by temporary gaps in the canopy at least 30 years before the study when the respective forest stands were gardens, a tree nursery, or a since-abandoned vegetatively restored sandpit. At that time, the trees had been able to produce a bank of root suckers and establish durably, forming a monospecific canopy that prevents the regeneration of other tree species. *A. altissima* could therefore be a threat, particularly since open habitats as well as natural or anthropogenic gaps in the canopy occur regularly (Motard et al. 2011).

At the landscape scale, invasive alien pathogens generally first colonise areas with continuous forests before eventually spreading to isolated or scattered forest stands or trees. Therefore, a landscape with diverse habitats may provide better resistance to alien pathogen invasions—though a scattered distribution of host trees will not always allow them to escape infection (Rigot et al. 2014). At the same time, natural forests with low levels of fragmentation are generally considered to be less prone to plant invasions than other modified ecosystems (e.g. agricultural systems), whereas forest fragmentation can promote plant invasions. *Pinus radiata* has been an extremely successful invader in diverse ecosystems of the Southern Hemisphere (Richardson et al. 1994), probably because of its rapid maturation, serotiny, resilience to fires, and the high ability of its seeds to disperse by wind. A study in Chile (Bustamante et al. 2003) highlighted the process of invasion in fragmented native forest close to *P. radiata* plantations, while *Acacia melanoxylon* (Gutiérrez et al. 2024) can be a successful invader in fragmented or human-disturbed riparian forests (Fig. 17.1).

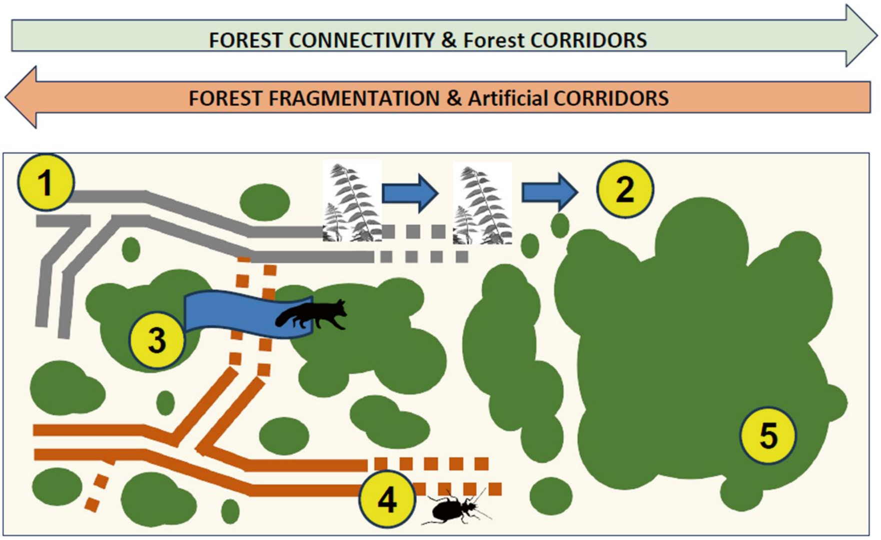

Fig. 17.1 Forest fragmentation is the splitting of large, contiguous forest areas and habitats (5) into smaller pieces of forest (green areas). Typically, these pieces are separated by several types of artificial corridors (e.g. railways (1), continuous and dotted grey lines, and roads (4), continuous and dotted brown lines in the figure), agricultural land, utility corridors, subdivisions, or other human-related land uses. Wildlife crossing (3) allows animals to cross human-made barriers safely. The fragmentation of forests is the main factor limiting their connectivity, and increasing forest connectivity is crucial for supporting biodiversity in forests. Clusters of small forest fragments can act as stepping stones. Railways can promote the spread of invasive alien trees such as *Ailanthus altissima* (2) reaching intact forest edges and roads and the spread of many insects (4) as hitchhikers

In 1999, the pinewood nematode *Bursaphelenchus xylophilus*, a causal agent of pine wilt disease that is native to North America and disperses naturally only with the aid of vector beetles of the genus *Monochamus*, was first detected in Europe—more precisely, in south-western Portugal and later at several sites in Spain and on Madeira Island. Since then, it has spread to more than 30% of Portugal, causing large-scale damage to the country's forests (De la Fuente et al. 2018). In a modelling study, De la Fuente et al. (2018) demonstrated that simulated clear-cut belts could stop the spread of the pinewood nematode only if they were wider than 30 km although thinner belts could delay the invasion. Furthermore, clear-cuts could be more effective in slowing down the invasion when combined with a reduction of the vector beetle population in the adjacent areas through mass trapping as well as with early detection and removal of infected trees. In the absence of effective containment measures, the pinewood nematode may naturally spread into Spain in about 5 years. In less than 10 years, it may reach the major forest and climatic corridors that provide a gateway for subsequent expansion towards the rest of the Iberian Peninsula and, in the longer term, towards other European countries (De la Fuente et al. 2018) (Fig. 17.2).

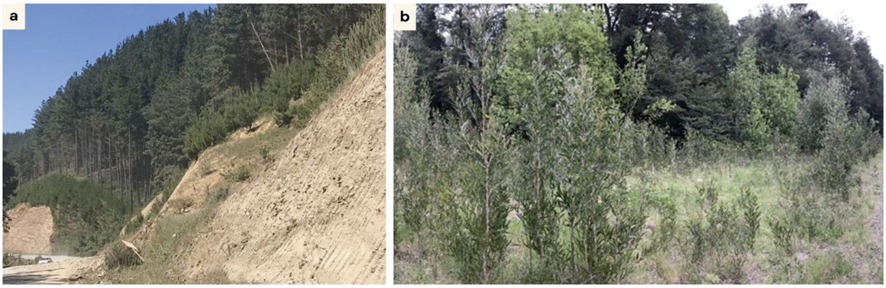

Fig. 17.2 (**a**) The colonisation of road verges by pine wildings within a large plantation of *Pinus radiata*. (**b**) The colonisation of a forest path by *Acacia melanoxylon* (Australian blackwood)

Prevention, Management, and Monitoring of Biological Invasions in Forest Corridors

Given that biological invasions in forests can be promoted or impeded by landscape features such as corridors (both by forest corridors and artificial corridors) and stepping stones, it is essential to incorporate this knowledge into predictions of IAS spread as well as into strategic management. The prevention of introductions and the management of IAS, whenever prevention fails, are fundamental components of any strategy aiming to conserve habitat connectivity in forest ecosystems. The impacts of IAS on connectivity can have serious negative consequences for biodiversity and ecosystem functions. Therefore, restoration efforts and effective management of IAS between habitat patches as well as within them are often necessary to improve connectivity. Importantly, IAS management can enhance landscape connectivity, and its incorporation into conservation planning may help to design optimal reserve networks. Conversely, conservation planning and connectivity modelling can optimise the targeting of IAS to achieve benefits for a wider range of taxa and ecological processes (Glen et al. 2013). The probability of IAS having an impact on forested stepping stones and corridors has been found to be influenced by various factors such as the proximity to urban areas, the age and degree of degradation of the forest stands, and climatic conditions (Basnou et al. 2016; Pino et al. 2013; Tello-García et al. 2021).

The decision to manage known, highly impactful IAS is often rather straightforward. However, prior to both the conservation and restoration of forest connectivity and forest habitat patches or forest corridors and when planning a new artificial corridor, a site-specific risk analysis should ideally be conducted. The aim of such an analysis is to assess the factual relationships between IAS and forest connectivity in the specific context, the potential impact of the present IAS on the functional and structural connectivity of the habitat patch, and the site-specific management needs and options available. Furthermore, if several IAS are present, prioritisation according to specific criteria may need to be conducted (e.g. McGeoch et al. 2016) or several species managed together to achieve the desired conservation or restoration outcomes. Importantly, several organisations, such as the Ministry of Transportation and Infrastructure, in partnership with the Invasive Species Council of British Columbia, provide invasive plant best practices from roadside maintenance operations. By applying these best practices, maintenance contractors can limit the introduction and spread of invasive plants. Besides employing the correct methods and techniques, an overall strategy based on landscape dynamics and expected spatial patterns can be fundamental to achieving success. This approach has been applied in the control of *Acacia dealbata* in a Natura 2000 site in Portugal, where Machado et al. (2022) showed that removing the patches with higher perimeter-to-area ratios (mostly small satellite patches) would be more impactful than removing larger patches or random patches with intermediate perimeter-to-area ratios first. Following this approach based on landscape dynamics, the employment of a connectivity assessment resulted in an ordered list of patches to remove sequentially (Machado et al. 2022).

If prevention fails and an alien species with the potential to become invasive has been detected in a habitat patch in a forest or close to a forest, prompt action is crucial. Outbreaks of serious or significant IAS require strategic-level plans ideally developed at a national level (contingency plans) that describe the overall aim and high-level objectives to be achieved and set out the response strategy to either eradicate or contain the IAS. Establishing a national or local action plan may be very time-consuming and should follow a standard procedure, for example, as suggested by the European and Mediterranean Plant Protection Organization (EPPO) in the standard PM 9/10 (1) (EPPO 2009). IAS eradication, control, or containment can be achieved using various methods, which can be employed and integrated into a dedicated management plan; each method has its own advantages and drawbacks depending on the biology and ecology of the IAS and the invaded landscape. For example, EPPO PM 9/29 (1) on *A. altissima* describes the control procedures aiming to monitor, contain, and eradicate *A. altissima* in the entire EPPO region (EPPO 2020). For small infestations, physical removal by manual uprooting or cutting of alien plants can be highly effective. However, for larger infested areas, the application of chemical, mechanical, and/or biological control measures is necessary to address the widespread presence of IAS. One straightforward example of the integration of methods is provided by Chabrerie et al. (2007) on *Prunus serotina*, where patch mosaic functional types (areas showing the same response to a plant invasion in a heterogeneous forest landscape) are used to predict invasion patterns in a forest landscape and produce a tailored management strategy that includes monitoring safe areas; extending cutting rotations; harvesting recently colonised stands tree by tree; promoting a multi-layered understorey vegetation; cutting down reproducing alien trees; favouring fast-growing, shade-tolerant native tree species; removing alien trees at the leading edge; and conducting soil enrichment or irrigation in heavily invaded areas.

Biological control methods (see also Chap. 17) involve the introduction of specialised natural enemies of an IAS such as insects or pathogens with the aim of reducing the population size or impeding reproduction of the IAS (Kenis et al. 2017). *Acacia longifolia* is native to Australia and was introduced into Europe between the late-nineteenth and early-twentieth centuries. Since its introduction in

Portugal, the species has become one of the most widespread IAS. It forms extensive populations within coastal ecosystems that displace native plant communities. Due to similar negative impacts recorded throughout its introduced range, the species has been the target of classical biological control using the Australian gall-forming wasp *Trichilogaster acaciaelongifoliae*. This biocontrol agent had previously been successfully employed in South Africa and was released in Portugal in 2015 (Dinis et al. 2020). Prior to releasing any biocontrol agents, a thorough assessment of risks and potential non-target effects is conducted, and regulatory approval is needed before implementation (e.g. EFSA Panel on Plant Health 2015 for *Trichilogaster*). Although biocontrol is not a full eradication of the target species, reducing its abundance may have an important effect on the native plant community and decrease the negative impact of the invader. Similarly, the use of chemical treatments, including herbicides or pesticides, should be approached with extreme caution. When chemical agents (PPPs—plant protection products) are used, they can pose risks to non-target species and the broader environment, as well as to the workers applying them. Therefore, their application should be limited, highly localised, and in line with national legislation on plant protection product (PPP) use. However, PPPs are often necessary since many woody species are able to re-sprout promptly, and thus mechanical methods alone are not effective.

Although one size does not fit all, managing heterogeneity in the landscape can have a positive effect on biodiversity. Similarly, ecological disturbances such as fire are important drivers of landscape heterogeneity that can promote diversity and create habitat structures required by certain species (Johnstone et al. 2016). International cooperation and the sharing of information and best practices are very important for the effective management of IAS in forests. The Food and Agriculture Organization (FAO) of the United Nations has helped to establish regional networks dedicated to the issue of forest pests—primarily forest IAS—and the forest sector. These networks aim to facilitate the exchange of information and mobilisation of resources; raise regional awareness; and act as links between experts, institutions, networks, and other stakeholders concerned with IAS in forests (https://www.fao.org/forestry-fao/pests/94102/en/). Furthermore, FAO provides guidelines for reducing the risk of invasive alien species in forest plantations (FAO 2006).

It should be remarked that forest patches, forest corridors, and artificial corridors, all might represent an opportunity for citizen science campaigns, i.e. for the collection and analysis of data relating to the natural world by members of the general public, typically as a part of collaborative projects with professional scientists. To fully qualify as citizen science, a project must not only rely on volunteers who participate in the detection process but also include the use of any number of tools (e.g. smartphone apps, collaborative databases, eDNA, or other technology). Using citizen science for early detection of invasive species in forests should always be an option in integrated strategies to tackle the issue. In recent times, citizen science has become possible at large scales due to the development of collaborative technology, social media and networking, and publicly accessible databases offering opportunities for anyone to participate in ecological research (Larson et al. 2020). However, not all IAS are easily surveyable by citizen science as some of them may be difficult to identify or can be found only in habitats less frequently scouted.

Furthermore, over the past decade, remote sensing has provided many important contributions to the progress of invasion science, improving our understanding of the drivers, processes, patterns, and impacts of alien species in all ecosystems (Vaz et al. 2019; Müllerová et al. 2023). For example, instruments such as light detection and ranging (LiDAR) and hyperspectral sensors are used to quantify forest characteristics at the stand-to-landscape level (Massey et al. 2023) more frequently and in combination with other methods of detecting and monitoring IAS or forest pests (Brockerhoff et al. 2023). The endemic Chilean tree *Araucaria araucana* (monkey puzzle tree) is classified as endangered in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species due to its decreasing population. In addition, it is considered a natural monument under Chilean law. The spread of propagules from alien forest plantations to surrounding native forests has been documented, with competition from alien saplings threatening the regeneration of endangered *A. araucana*. In fact, using freely available medium-resolution Sentinel-2 optical satellite imagery, Martin-Gallego et al. (2020) monitored alien trees wilding from plantations within the Chilean Valdivian temperate forest, whose extent and topography limit traditional ground-based methods, achieving high levels of mapping detail and accuracy (Figs. 17.3 and 17.4).

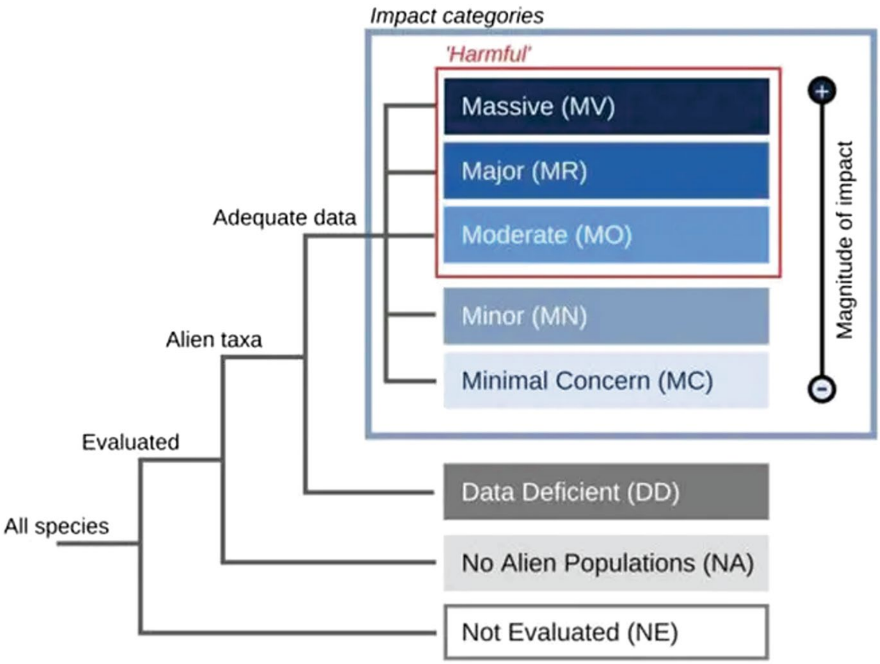

Fig. 17.3 There are eight categories for classifying taxa. The first five, known as "impact" categories, describe the increasing levels of harm caused by alien species on native biota: MC indicates negligible impact; MN suggests reduced performance; MO indicates population decline; MR denotes local extinction with potential for reversal; and MV indicates irreversible extinction and significant community structure change. DD is used when alien populations exist, but no evidence of impact is available, and the impact level is unknown; NA is used when there is no evidence of individuals outside of captivity or cultivation beyond a species' native range; and NE refers to unevaluated taxa. (IUCN 2020)

Fig. 17.4 The invasive Australian gall-forming wasp *Trichilogaster acaciaelongifoliae*. (Photo: Vuk Vojisavljevic/iNaturalist/Flickr)

Box 17.1 Impact Assessment and Risk Analysis

Identifying the most harmful or potentially harmful alien species for the ecological connectivity of a forest is a crucial step for effective management. It is therefore highly recommended to conduct standardised impact assessments for the alien species present at a site, ideally with site-specific information on impacts.

The Environmental Impact Classification for Alien Taxa (EICAT), a standardised scoring system that classifies alien species according to the severity of their environmental impact in recipient areas, has been adopted by the International Union for Conservation of Nature (IUCN). This system considers the level of biological organisation impacted with regard to native species, as well as the potential reversibility of the impact (Hawkins et al. 2015; Kumschick et al. 2017, 2020a). EICAT offers an objective and transparent way of categorising alien species based on the degree of harm they cause to the environment in the areas they invade. Evidence of the negative effects of these species on native organisms in their introduced range is used to classify them into one of five impact categories ranging from no impact on native individuals to irreversible local population extinctions. Additionally, EICAT includes a mechanism for classifying alien species based on the specific ways in which they cause harm (IUCN 2020).

Furthermore, site-specific risk analyses including information on impacts as well as on invasion potential and management aspects are recommended to

(continued)

reach the most suitable management decisions (e.g. Kumschick et al. 2020b; Booy et al. 2017). Such analyses are key for determining which species pose the greatest threat to a forest's ecological integrity and connectivity. By conducting a thorough evaluation, managers can develop effective strategies to mitigate the negative impacts of IAS and preserve the health of the forest ecosystem (Bindewald et al. 2021).

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