Curbing the major and growing threats from invasive alien species is urgent and achievable

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This Perspective highlights the global consensus on the urgency and growing threat of invasive alien species, and management needs, as found by the 2023 report on invasive alien species conducted by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

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Title: Curbing the major and growing threats from invasive alien species is urgent and achievable

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While invasive alien species have long been recognized as a major threat to nature and people, until now there has been no comprehensive global review of the status, trends, drivers, impacts, management, and governance challenges of biological invasions. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) thematic assessment report on invasive alien species and their control (hereafter "IPBES invasive alien species assessment") drew on more than 13 000 scientific publications and reports in 15 languages as well as Indigenous and local knowledge on all taxa, ecosystems, and regions across the globe. It, therefore, provides unequivocal evidence of the major and growing threat of invasive alien species alongside ambitious but realistic approaches to manage biological invasions. The extent of the threat and impacts has been recognised by the 143 member states of IPBES who approved the summary for policymakers of this assessment. Here, the authors of the IPBES assessment outline the main findings of the IPBES invasive alien species assessment and highlight the urgency to act now.

Introduction

Invasive alien species (Box 1) are one of the major drivers of ongoing global biodiversity loss, adversely impacting people and nature in all regions of Earth[1,2]. Invasive alien plants, animals and other organisms have drastically altered ecosystems around the world[3], caused homogenization of biota at a global scale[3], and have contributed to 60% of known extinctions[1]. Biological invasions have also come at a huge cost to people, with invasive alien species threatening health and livelihoods around the world[1]. The annual global economic cost of biological invasions has been quadrupling every decade since 1970 and exceeded USD423 billion in 2019, a very conservative estimate based on the available data and not including societal and cultural costs which are largely intangible[1,4].

The IPBES invasive alien species assessment is a pivotal landmark in addressing this major driver of biodiversity loss and represents a first step towards a new era of research, management, and policy for biological invasions. By comprehensively synthesizing and assessing available global information on biological invasions across diverse ecosystems and taxa, the assessment sheds light on the urgency of the problem, providing a foundation for targeted actions in prevention and control. The report also identifies areas where data deficiencies must be addressed, highlighting policy mismatches and needs.

Addressing biodiversity loss will only be possible through dedicated commitment to managing biological invasions and the interactions of invasive alien species with other drivers of biodiversity loss. The impacts of invasive alien species are overwhelmingly negative[5]. However, the magnitude of the threat of biological invasions should not obscure the tangible successes of many management actions around the globe, including the eradication of invasive alien species on many islands and classical biological control. Acknowledging these achievements, it is crucial to emphasize that the impacts of invasive alien species would be even more severe without the preventive and remedial actions already undertaken. While evidence-based science, management, and policy options exist to address the growing challenge of biological invasions, as outlined in the IPBES invasive alien species assessment, their effectiveness relies on a robust commitment at both international and national levels.

Global consensus on the urgency and growing threat of invasive alien species

At least 37,000 established alien species (Box 1) have been introduced by human activities beyond their natural range to all regions (Figure 1) and biomes of Earth, including remote and isolated environments [1]. A subset of these established alien species become invasive alien species[6] – that is, globally, more than 3,500 established invasive alien species[3,5]. Islands, and particularly remote islands with high endemism, are highly susceptible to impacts from invasive alien species, with 90 per cent of documented global extinctions attributed mainly to invasive alien species occurring on islands. As an example, *Boiga irregularis* (brown tree snake) caused the extinction of almost all forest birds in Guam[7] including the global extinction of *Myiagra freycineti* (Guam flycatcher)[1,7].

The threats posed by invasive alien species are expected to continue to rise[3,8]. An increasing number of species are being transported beyond their natural ranges into new areas through a wide range of human activities[3,9]. Every year, approximately 200 new alien species are now being introduced globally by human activities to regions they had not been recorded before[3]. There is a strong link between the volume of commodity imports and the number of alien species in a region, and patterns in the global spread of species mirror shipping and air traffic networks[3,9]. Many invasive alien species have been unintentionally introduced as contaminants of traded commodities, for example as stowaways in ballast water and sediments, or via biofouling on vessels. The strong growth in e-commerce over the last decade has led to the online trade in animals and plants, including illegal trade, becoming an increasingly important route for the introduction of alien species[9]. It is likely that a continued growth in human populations, trade, travel, and land- and sea-use change will lead to a continued increase in the number of alien species introductions worldwide[9]. Assuming past trends in drivers of biodiversity loss continue, the total number of alien species is expected to increase by 36 per cent by 2050 relative to 2005[3]. However, patterns in the numbers of alien species seen today reflect the drivers prevalent decades ago due to delays in demographic and evolutionary responses to drivers alongside time lags in recording and reporting of new occurrences. Consequently, past drivers, and the ongoing amplification of those drivers, may lead to a long future legacy of invasive alien species (i.e., invasion debt)[3].

Even without the introduction of new species, already established alien species will continue to expand their geographic ranges and spread into new countries and regions, with many causing negative impacts[3]. Some invasive alien species spread very rapidly, and their impact is immediate and continues into the long-term, e.g., fast-spreading pathogens such as Zika virus and *Batrachochytrium dendrobatidis* (chytrid fungus) and fast-spreading predators such as *Pterois* spp. (lionfish). Other invasive alien species take longer to spread and fully occupy their potential ranges, and there can be a considerable time lag before impacts are apparent (e.g., it can be decades before the impacts of invasive alien trees and marine invasive alien species are recorded). Therefore, simple extrapolations from the impacts of invasive alien species observed today are likely to underestimate the magnitude of future impacts.

Interactions among drivers of biodiversity loss are amplifying biological invasions

No driver acts in isolation. Climate change is a major driver facilitating the establishment and spread of invasive alien species into previously inhospitable regions[9]. For example, climate warming is enabling aquatic and terrestrial invasive alien species to establish and spread poleward, including into the Arctic and Antarctic regions. Also, in some mountainous regions, climate change, acting together with other drivers of biodiversity loss, has allowed invasive alien species to extend their ranges into higher elevations twice as fast as native species[9]. Land-use and sea-use change may create corridors along which invasive alien species may spread while also causing disturbances to native habitats making such habitats less resistant to invasive alien species[9]. Climate change, including the impacts of extreme events (such as droughts, floods, wildfires, tropical storms, and oceanic storm waves) is exacerbating this trend with ecosystems becoming less resistant to invasive alien species[8]. Similarly, invasive alien species exacerbate the impacts of climate change. For example, fire-adapted grasses are fuelling wildfires catalysed by climate change and leading to further biological invasions[10].

Prevention is the best option for managing biological invasions

The IPBES invasive alien species assessment embraces the complexities of biological invasions and puts forward options to effectively address the growing threats and negative impacts of invasive alien species (Figure 2). Many potential future biological invasions can be prevented[8,11]. Indeed, prevention remains the most cost-effective option for reducing the threats from biological invasions compared with the investment needed to implement appropriate management actions to counter negative impacts once invasive alien species are established[11,12]. Prevention can be achieved through pathway management (including effective import controls, border biosecurity, and quarantine services) but this requires long-term resourcing and capacity-building nationally and globally[9,11,13]. Extensive public communication and engagement strategies are also critical to achieving prevention[11].

There are many decision support tools available to identify and prioritize invasive alien species with risk analysis and horizon scanning being amongst the most important[14]. Such tools underpin prevention and should be undertaken not only by governments but also by private and public industries[15]. Adopting regulated export and import species lists is also vital[1]. National legislation and international regulations for trade and biodiversity conservation should focus on prevention across health (animal, plant, human and environmental) sectors and promote commitment and cooperation amongst a wide range of stakeholders and Indigenous Peoples and local communities. National Invasive Species Strategies and Action Plans (NISSAPs) are critical to ensure the effectiveness of strategies for preventing biological invasions and controlling invasive alien species.

Other tools are available when prevention is not possible

Preparedness for when prevention fails is equally critical, including national surveillance strategies (e.g., through community (citizen) science or sentinel sites) for early detection of new alien species, supported by decision-support tools alongside accurate diagnostic and support services[11] and readily available funding to undertake management actions. Strategies are needed to enable rapid response upon detection to eradicate or contain populations of invasive alien species before they spread. While prevention and preparedness work best hand in hand, eradication, containment, and control of established invasive alien species have also been effective in limited, specific contexts. Eighty-eight per cent of 1550 documented examples of eradication of invasive alien species were successful, particularly involving vertebrates on islands[1]. Eradication can also be successful in some other situations, including large land masses, when supported by evidence-based best practices[14]. Classical biological control has been successful for invasive alien plants and invertebrates in more than 60 per cent of 347 documented programmes, with 60% of invertebrates and at least one third of the alien plant species requiring no further form of control[1]. However, there is no doubt at present eradication is extremely costly and success rates are extremely low for widely distributed invasive alien species within continental habitats and ecosystems. In marine environments, eradication is almost impossible to achieve[11]. Emerging tools and technologies, including genetic approaches such as eDNA and CRISPR, may increase the feasibility of eradication but prevention remains the best option[11].

The development of next generation tools and technologies such as genetic control approaches and novel biopesticides are being developed under a precautionary approach[11]. Artificial intelligence is also supporting surveillance, remote sensing, decision making, and robotic control tools[11]. Site and ecosystem management supported by restoration are improving management outcomes by enhancing ecosystem function and resilience. As an example, restoration can reverse the long-term adverse effects of invasive alien *Phragmites australis* on faunal communities in marshlands over relatively short time scales[16]. Ultimately, the success of any management programme depends on the availability of adequate and sustained resources, including for building research and management capacity, which are generally unevenly distributed amongst countries.

Management benefits from engagement with stakeholder and Indigenous Peoples and local communities

Development and implementation of relevant policies for the management of biological invasions has, in some cases, been hindered by differing perceptions of the importance and urgency of the threat of invasive alien species, coupled with lack of awareness of the need for collaborative action. The IPBES invasive alien species assessment is a landmark in this regard, as it is the first global consensus that the threat of biological invasions is major and requires urgent cross-sectorial cooperative and collaborative action. The next step should be to invite engagement by government and private sector stakeholders, and Indigenous Peoples and local communities, to co-develop management actions. It is important that such actions consider ways to optimise economic, environmental, and social outcomes and social acceptability, particularly where there are conflicting perceptions of the value of invasive alien species and the ethics of management options. The lands of Indigenous Peoples and local communities are critical for protecting nature and are often especially vulnerable to the impacts of invasive alien species. Interestingly, globally Indigenous Peoples' lands host up to 30% fewer alien species (approximately 2,300 species) than other areas except, unsurprisingly, where Indigenous Peoples' lands proximate to urban areas [17]. Indigenous lands in Oceania and North America have particularly high numbers of recorded invasive alien species[3]. While the reasons for the reduced numbers of alien species are in part due to lower levels of disturbance and remoteness, they remain lower even after controlling for these factors. The experience and accumulated wisdom of Indigenous Peoples and local communities as well and differing biocultural views on the value of invasive alien species should be considered according to Collective benefit, Authority to Control, Responsibility, Ethics (CARE) principles [18] and Free Prior and Informed Consent, as leading to improved outcomes for management. Management actions benefit from sharing knowledge and information[6]; recognizing the knowledge, rights and customary governance systems of Indigenous Peoples and local communities improves long-term management outcomes[11].

Engagement of the general public through awareness raising campaigns, education and community science platforms also contributes to establishing shared responsibilities in managing biological invasions including enhancing biosecurity through management campaigns (e.g., awareness raising initiative, co-developed by people from more than 50 organisations, Beware of Aliens https://easin.jrc.ec.europa.eu/easin/BewareofAliens) and early detection of invasive alien species. Indeed, community science initiatives, supported by digital identification tools, have supported the early detection of *Halyomorpha halys* (brown marmorated stink bug) in Europe[19] and New Zealand[20]. Similarly records submitted by the public through the Asian Hornet Watch app in the UK are making a major contribution to *Vespa velutina* (Asian hornet)early-detection and rapid response (EDRR) . Widespread access to recording platforms (e.g., iNaturalist and SIS-Geo) including those available on smartphones supports these activities enabling people to report invasive alien species[21].

Information sharing is needed across borders and within countries

Understanding the process of biological invasions allows us to recognize the complex relationships between various social and ecological systems that characterise biological invasions and their management (Figure 2). International, national, and local agencies involved in developing and implementing policies for key sectors (agriculture, aquaculture, forestry, the environment, community and regional development and health) responsible for a large number of invasive alien species can all play a role in developing coherent approaches to preventing and controlling biological invasions at different spatial and temporal scales. Coordinating bodies can enable collaboration and implementation. An example of such a multilateral coordinating body is the Antarctic Committee for Environmental Protection (CEP) which has developed a Non-Native Species Manual for activities of the countries active in the Antarctic[8,22]. International partnerships can share the responsibility of risk analysis and help to prioritize specific actions, including strengthening of detection of invasive alien species and rapid response capacity.

Open, regularly updated, and interoperable information systems will improve the coordination and effectiveness of management of biological invasions within and across countries. In recent years there has been considerable progress in developing standards, workflows, and infrastructures for integrating information sources on invasive alien species[23,24]. For example, occurrence records and species checklists are being integrated across online platforms such as Global Biodiversity Information Facility (GBIF), Ocean Biodiversity Information System (OBIS) and Global Register of Introduced and Invasive Species (GRIIS). Such advances in data processing and information flows have underpinned the analysis of patterns and trends reported within the IPBES invasive alien species assessment and will be invaluable for ongoing large-scale assessments of biological invasions and, specifically, for delivering indicators to assess progress[8,25] towards Target 6 of the Kunming-Montreal Global Biodiversity Framework.

Coordinated efforts to strengthen national regulatory instruments, including those for e-commerce and for the responsible use of technologies to prevent and manage biological invasions, are priorities. Market-based instruments such as tax relief and subsidization can be used to incentivize action and spur relevant investment. Assigning appropriate responsibility and accountability across sectors for prevention, control, and environmental liability, is integral to the effective management of biological invasions[8]. Existing approaches (e.g., One Health) could provide frameworks for cross-disciplinary thinking to develop and implement regulatory and policy instruments that contribute to the management of biological invasions. One Biosecurity is a concept, building on One Health, that proposes approaches for connecting human, animal, plant, and environmental health to effectively prevent and mitigate the impacts of biological invasions[26].

Need for commitment to comprehensive and truly global information systems

The IPBES invasive alien species report provides a comprehensive overview of knowledge gaps identified through the assessment and many relate to bias in available information and ensuring interoperability of information systems. Increasing access to the most up-to-date data and information and continuously filling major knowledge gaps on biological invasions, particularly in developing countries, will lead to more robust and effective policy instruments and management actions. As already stated there are a number of accessible and open sources of information (e.g. Global Register of Introduced and Invasive Species[27]). However, there are substantial knowledge gaps and limitations in accessing and mobilising information, particularly for some taxonomic groups (invasive alien invertebrates and microorganisms), environments (marine), and regions (some parts of Africa and Central Asia). Enhancing research capacity in some regions and collaboration between experts in the developed and developing world will improve data and information availability. There is also a need to integrate information across knowledge systems, disciplines, and sectors. Our understanding of the context-specific features of biological invasions, to inform action and ultimately mitigate the impacts of invasive alien species globally, will depend on building capacity to deliver rapid flow of relevant and comprehensive information.

Aspirational and ambitious goals can be achieved

The IPBES invasive alien species assessment provides the evidence-base and options to inform immediate and ongoing action to address the major and growing threat of biological invasions. Ultimately implementation of strategic actions (Figure 2), with strong commitment at international and national levels, will lead to significant progress towards Target 6 of the Kunming-Montreal Global Biodiversity Framework adopted by the Conference of the Parties of the Convention on Biological Diversity to eliminate, minimize, reduce, and /or mitigate the impacts of invasive alien species on biodiversity and ecosystem services.

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Authors contributions

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Ethics declaration

Not applicable.

Competing interests

The authors declare no competing interests.

Box 1. The biological invasion process and definitions of alien, established alien and invasive alien species
Biological invasion – a process that transports (moves) and introduces a species outside of its natural range, intentionally or unintentionally by human activities to new regions where it may become established and spread
Alien species – A species whose presence in a region is attributable to human activities that have enabled it to overcome the barriers that define its natural range
Established alien species – A subset of alien species that have produced a viable, self-sustaining population and may have spread
Invasive alien species – A subset of established alien species that spread and have a negative impact on biodiversity, local ecosystems and species. Many invasive alien species also have impacts on nature's contributions to people (embodying different concepts, such as ecosystem goods and services and nature's gifts) and good quality of life

Table 1. Options for strengthening the governance of biological invasions at national, regional and global scales.

Indication of the approximate time frame to initial implementation and the duration of investment needed to implement different options. This table presents concrete options for action and complements the strategic actions outlined in figure 2 which underpin an integrated governance approach[1].

Figure 1. Global distribution and temporal trends in established alien species

There is evidence of negative impacts for 3500 of the established alien species and this subset is termed invasive alien species. (A) Total numbers of established alien species (terrestrial and freshwater) in the regions (consisting of countries and subnational units) and marine ecoregions (marine) are indicated. White denotes missing information. A gap analysis was conducted to identify data gaps for terrestrial regions, which are indicated in the inset. The data gap analysis could not be done for marine regions (white) and Antarctica (grey). (B) The temporal trends in the number of established alien species from 1500 to 2015 are shown for mammals, birds, fishes, insects, crustaceans, molluscs, vascular plants, algae and fungi, for the four IPBES regions[1].

Figure 2. Integrated governance for the management of biological invasions

An integrated governance approach includes specific strategic actions that promote transformative change to meet the goals of preventing and controlling biological invasions and ultimately fulfil the 2030 mission of the Kunming-Montreal Global Biodiversity Framework. Understanding the varied **contexts and complexities** (across stages of biological invasion, across ecological levels from individuals to ecosystems, across multiple spatial and temporal scales, across levels of governance and interactions amongst drivers of biodiversity loss) is critical to achieving ambitious progress towards managing biological invasions. Implementation of management actions can lead to sustained outcomes (including border biosecurity, prevention and preparedness, risk analysis, prioritisation, and decision-making, surveillance and monitoring, eradication and containment, chemical, physical and biological and adaptive management) with benefits for people and nature that not only reduce the threat of biological invasions but also increase the effectiveness of policies and actions designed to respond to other drivers of biodiversity loss. Adapted[1]

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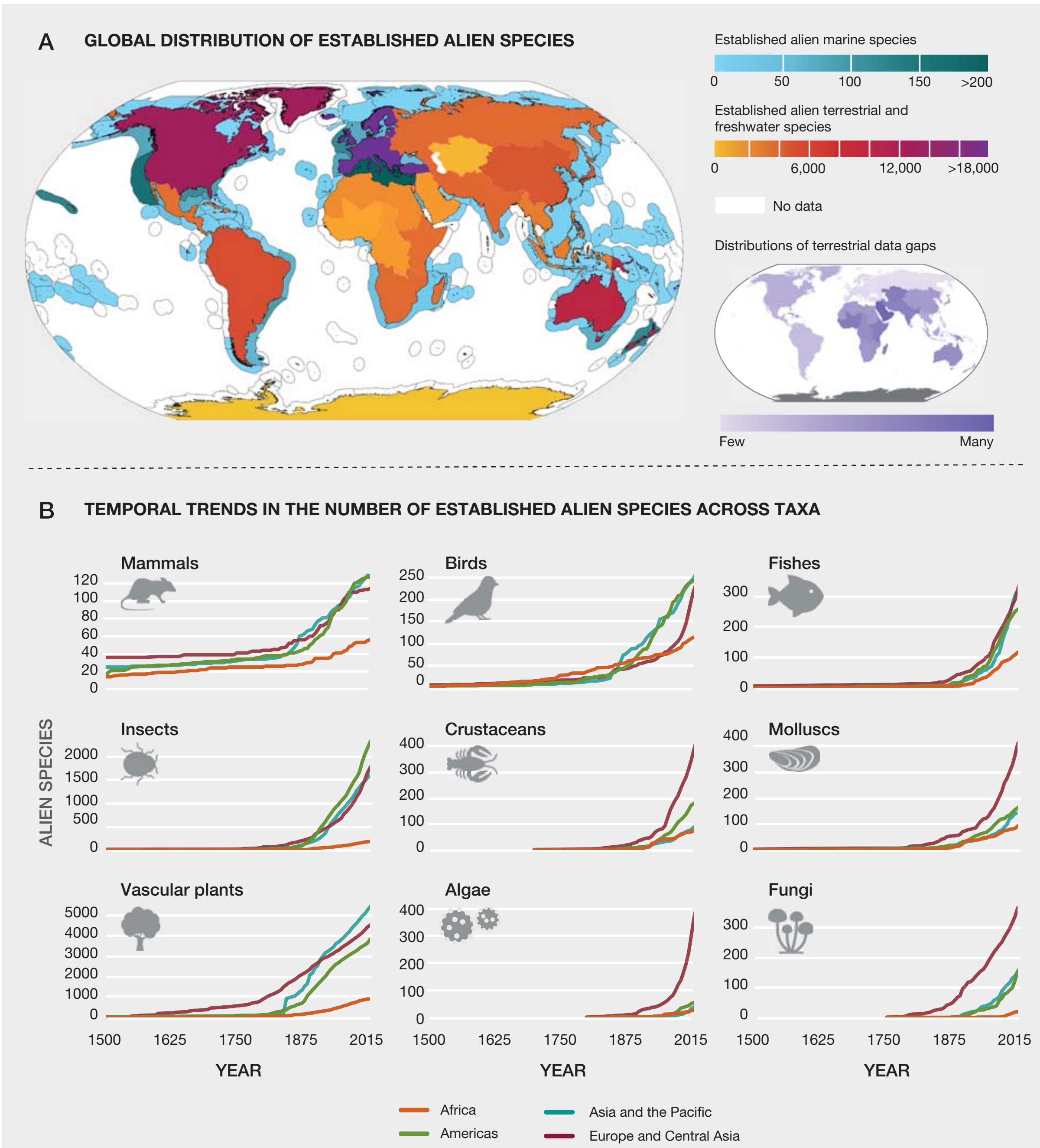
A GLOBAL DISTRIBUTION OF ESTABLISHED ALIEN SPECIES
Established alien marine species
0 50 100 150 >200
Established alien terrestrial and freshwater species
0 6,000 12,000 >18,000
No data
Distributions of terrestrial data gaps
Few Many
B TEMPORAL TRENDS IN THE NUMBER OF ESTABLISHED ALIEN SPECIES ACROSS TAXA
Mammals
Birds
Fishes
Insects
Crustaceans
Molluscs
Vascular plants
Algae
Fungi
ALIEN SPECIES
YEAR
1500 1625 1750 1875 2015
Africa
Americas
Asia and the Pacific
Europe and Central Asia


Strategic actions
Enhance coordination and collaboration across international and regional mechanisms
Develop and adopt effective and achievable national implementation strategies
Improve policy coherence
Share effort and commitment; understand specific roles of actors
Engage broadly across all stakeholders and Indigenous Peoples and local communities
Resource innovation, research and technology
Support information systems, infrastructures and data sharing
Context and complexities
Across stages of biological invasion
From individuals to ecosystems
Across temporal and spatial scales
Across levels of governance
Interacting drivers of biodiversity loss
Management actions
Border biosecurity
Preparedness
Risk analysis, prioritisation, and decision-making
Surveillance and monitoring
Eradication / containment
Chemical, physical and biological controls
Adaptive management including access to modern tools and enhancing capacity to deploy them
Outcomes
Ambitious progress towards United Nations Sustainable Development Goals and the Kunming-Montreal Global Biodiversity Framework adopted by the Conference of the Parties of the Convention on Biological Diversity

Governance purpose	Options	Duration of investment needed
Coordination and resourcing	Enhance multilateral coordination and collaboration to support the integrated governance of biological invasions	Ongoing
	Engage broadly across affected and responsible parties	Ongoing
	Build capacity to enable strategic actions	Ongoing
Policy	Share efforts, commitments and understanding of the specific roles of all	Short
	Strengthen compatibility of relevant regulatory instruments	Periodic
	Use national strategy and planning for invasive alien species to achieve policy implementation	Periodic
	Support, fund and mobilize resources for innovation, research and environmentally sound technology	Ongoing
	Support information systems, infrastructures and open and equitable access to information on invasive alien species	Short
Research, information, and technology	Invest in information systems for invasive alien species for information-sharing within and across countries	Ongoing
	Maintain up-to-date information on necessary and enabling indicators	Ongoing
	Monitor policy and management effectiveness and resourcing levels	Ongoing
	Develop new solutions through research and technology	Ongoing

Short Periodic Ongoing