Chapter 6

GOVERNANCE AND POLICY OPTIONS FOR THE MANAGEMENT OF BIOLOGICAL INVASIONS[1]

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Chapter **6**

GOVERNANCE AND POLICY OPTIONS FOR THE MANAGEMENT OF BIOLOGICAL INVASIONS

EXECUTIVE SUMMARY

1 Despite some successes over the past decade, there has been limited progress towards meeting international goals and targets for biological invasions, such as Aichi Target 9 of the Strategic Plan for Biodiversity 2011-2020 and Target 15.8 of the 2030 Agenda for Sustainable Development *(well established)* {6.1.2} (Table 6.4). Many countries have little or no funding for activities to prevent or control biological invasions *(well established)* {6.1.3}, and most national invasive alien species targets lack sufficient ambition to substantively contribute to the achievement of Aichi Biodiversity Target 9 *(well established)* {6.1.2, 6.3.3}. Legislative and other policy instruments addressing biological invasions and their implementation vary greatly across countries *(well established)* {6.1.2} and sectors within countries *(well established)* {6.3.1.1, 6.3.3.1}. Data for assessing the effectiveness of pathway- and species-management are mostly unavailable *(well established)* {6.6.1.2}, highlighting the need for the generation of new and up-to-date information on the appropriate level of implementation and on the successes and failures of management interventions {6.6.1, 6.7.2.6}. Furthermore, there is limited dedicated interdisciplinary research on the governance for biological invasions in a broader environmental governance context *(well established)* {6.2.2, 6.3.3.3, 6.6.1.4}.

2 Effective governance for biological invasions can address policy gaps and limits, and improve policy coherence and its implementation *(well established)* {6.2.3, 6.7.2.3}. This could be achieved with a context-specific integrated governance approach for biological invasions, that focuses on coordinated and sequential implementation of strategic actions *(established but incomplete)* {6.2.4, 6.7.2}. Integrated governance can be achieved through robust institutions that are responsive to changing contexts, and strategies to ensure effective implementation of strategic actions *(well established)* {6.7.3} **(Figure 6.21)**. A conducive environment for integrated governance is equitable and respects different value systems and perspectives *(well established)* {6.7.3} **(Figure 6.21)**. This in turn promotes inclusive decision-making, shared efforts and commitments, the understanding of specific roles of all actors, catalyses the sharing of knowledge, data and resources, and promotes the development and implementation of multidisciplinary solutions *(well established)* {6.7.2} **(Figure 6.21)**. Integrated governance includes explicitly considering negotiation and trade-offs as an integral part of the process *(established but incomplete)* {6.2.2} **(Figure 6.21)**. By focusing on the relationships between the scales, levels of governance, sectors and stakeholders involved, the integrated governance approach identifies and addresses feedbacks, efficiencies and trade-offs in the management of biological invasions *(well established)* {6.2.4, 6.2.3.3, 6.7.2, 6.7.3} **(Table 6.7)**.

3 Multilateral coordination and cooperation are key for bringing about progress towards achieving invasive alien species goals and targets, and coherent, mutually supportive actions *(well established)* {6.2.3.3, 6.3.2.3, 6.4.4, 6.7.2.2}. Widespread and purposeful cooperation could improve the effectiveness of policy instruments to prevent and control invasive alien species *(well established)* {6.3.2.3, 6.7.2.2}. The need for cooperation emerges from the diversity of stakeholders and perspectives involved {6.4.1}; problems created by uncoordinated responses and little-considered trade-offs across sectors {6.3.1.1, 6.7.2.2}; the multiple geopolitical scales at which policy and management are needed {6.3.2}; widespread economic constraints in some regions {6.1.3}; and the interdependence between invasive alien species and other drivers of change in nature {6.3.1.3, 6.7.2.2} *(established but incomplete)*. Strategies for achieving such cooperation and for managing the collective action costs of widespread collaboration can include: enhancing coordination and collaboration across international and regional mechanisms {6.2.3.4, 6.7.4}; long-term resourcing, including developing the capacity needed, and commitment from governments and institutions at the highest levels {6.2.3.2, 6.5.1, 6.7.2.3} **(Table 6.1)**. Other options to accelerate progress include research on the relationships between actors and institutions {6.6.1}; engagement of the general public including awareness campaigns {6.2.3.3, 6.4.2.2, 6.6.2.1}; inclusion of Indigenous Peoples and local communities and recognition of their rights {6.4.3.1, 6.4.3.2, 6.6.1.5}, and information platforms to support decision-making that are developed and sustained for the long-term *(established but incomplete)* {6.2.3.1(3), 6.6.2}.

4 One of the most effective ways to manage biological invasions is to develop policy instruments that seek synergies between human health, agriculture, forestry, fisheries and environment sectors at national and international levels *(established but incomplete)* {6.1.2, 6.3.1.1}. Many national laws and regulations, as well as multilateral agreements, aimed at preventing the introduction of invasive alien species have been adopted *(well established)* {6.1.2}. They have jointly contributed to reducing the risk of invasive alien species' impacts on nature's contributions to people and good quality of life *(well established)* {6.1.2}. However, there are still gaps, limitations, and inconsistencies in the scope, taxonomic coverage, procedures and standards of current policy instruments both within countries and across regions *(well established)* {6.2.2}. Close collaboration between the different national agencies overseeing trade policy, agriculture and forestry, the environment and health can deliver a coordinated approach to biological invasions *(well established)* {6.3.1.1}. Existing approaches for achieving the necessary coordination (such as EcoHealth, One Health and One Biosecurity approaches) provide frameworks for cross-disciplinary thinking in support of the development and implementation of policies and policy instruments *(established but incomplete)* {6.3.1.1, 6.7.2.2}. While economic incentives can potentially enhance compliance with biosecurity protocols *(established but incomplete)* {6.5.2.1}; financial deterrents in the form of tariffs and penalty systems can also be used to prevent mismanagement of species introductions and the revenues they generate as means to fund incentives and/or government control programmes *(established but incomplete)* {6.5.2.2, 6.5.2.3, 6.5.3, 6.5.4, 6.5.6}. Governance for biological invasions would also benefit from the expansion of dedicated inter- and transdisciplinary research *(well established)* {6.2.4, 6.6.1.4}. Research on the impacts of invasive alien species across the health, agriculture, forestry, fisheries and environment sectors could support the development of coherent policy instruments *(established but incomplete)* {6.2.4} **(Table 6.2)**.

5 Implementation-focused national strategies and action planning for biological invasions, aligned with international regulatory frameworks, could stimulate action and help improve the effectiveness and efficiency of management efforts *(well established)* {6.2.3.2, 6.3.3.1, 6.7.2.3}. Implementation-focused strategies and action plans can provide enabling conditions for the successful governance of biological invasions, including coordination and collaboration across international and regional mechanisms *(established but incomplete)* {6.2.4, 6.7.3}, legal, regulatory and institutional frameworks {6.3.3.1}, market-based instruments that provide economic incentives and deterrents {6.5.2} and multisector inclusion {6.2.3.3, 6.3.1.1}. These national strategies could prioritize the measurement and monitoring of the resource inputs, processes, outputs and outcomes needed to improve implementation and accelerate progress towards meeting invasive alien species goals and targets at multiple levels of governance *(established but incomplete)* {6.2.3, 6.3.3.3, 6.6.2, 6.6.3, 6.7.2.6}. National strategies can define the governance models, policy instruments and support tools needed to ensure shared efforts and commitments, and understanding of the specific roles of all actors *(well established)* {6.2.3.2, 6.7.2.5} and include plans for the effective engagement across private and government stakeholders and Indigenous Peoples and local communities *(established but incomplete)* {6.4.3, 6.6.1.5, 6.7.2.4, 6.7.2.5}. They can also include market-based instruments to fund and promote activities to prevent and manage biological invasions in national budgets *(established but incomplete)* {6.5.2, 6.5.3, 6.5.4, 6.5.6} and ensure the efficient use of resources for biological invasions *(well established)* {6.2.3.2, 6.2.3.4, 6.3.3.2, 6.7.2.2}. National strategies provide a mechanism to operationalize the Convention on Biological Diversity's fifteen guiding principles for the prevention, control and mitigation of impacts of invasive alien species, which remain highly relevant but are not yet adequately implemented *(well established)* {6.1.2, 6.2.3.2, 6.3.3.3, 6.7.2.3}. National strategies are central to guiding actions to implement context-specific integrated governance for addressing biological invasions *(established but incomplete)* {6.2.4, 6.7.1}.

6 An open, interoperable information platform can effectively support changing information needs on biological invasions and enable the rapid flow of information for decisions across international, national and local levels *(well established)* {6.6.2.3, 6.6.2.4, 6.6.3, 6.7.2.6}. Such a platform could ensure that knowledge is readily available to all stakeholders involved in addressing biological invasions, particularly for those whose actions are currently limited by a lack of resources *(well established)* {6.6.2.3, 6.6.3, 6.7.2.6}. Integrated data workflows and rapid data publication could considerably reduce the time lag between the establishment of evidence and making the evidence available for a wider community and for policy, including regarding Target 6 of the Kunming-Montreal Global Biodiversity Framework *(well established)* {6.6.2.3}. Conforming to the data principles of findability, accessibility, interoperability and reusability (FAIR) makes data easier to access and use for monitoring, modelling and forecasting *(established but incomplete)* {6.6.2.4}. Continuously collecting and sharing up-to-date information on biological invasions can help evaluate the effectiveness of policy instruments and management actions *(established but incomplete)* {6.6.2.3, 6.3.3} and improve management outcomes *(well established)* {6.6.2, 6.6.3, 6.7.2.3}. Such an information platform could maintain and deliver indicators of the different dimensions of biological invasions to track progress at national and global scales, and in the medium to long term as part of a responsive and adaptive policy

environment {6.1.2, 6.1.3, 6.2.3, 6.6.3, 6.7.2.6} *(well established)*. Targeted investment in specific research and monitoring programmes can rapidly and effectively deliver relevant data and information for policies and management of biological invasions *(well established)* {6.6.2, 6.7.2.6}.

7 Committed engagement with stakeholders and Indigenous Peoples and local communities can benefit the management of biological invasions by improving understanding and awareness, social learning, collaboration, surveillance and data generation *(well established)* {6.2.3.3, 6.4.2.1, 6.7.2.6}. Inclusive engagement can help build policy and management plans to address biological invasions that are coherent, legitimate and reflect local environmental and cultural realities. Adaptive-collaborative governance can foster collaboration and coordination grounded in disciplinary integration, experimentation, monitoring, the use of the best available technology and social learning *(established but incomplete)* {6.2.3.3, 6.4.3}. Engagement activities can be explicitly linked with the measurement and monitoring of management actions through national strategies aimed at enhancing respect for Indigenous Peoples and local communities' knowledge, rights and priorities *(established but incomplete)* {6.4.1, 6.4.3.2}. Biocultural community protocols developed by Indigenous Peoples and local communities can frame how they wish to be engaged in the activities that impact them *(established but incomplete)* {6.4.3.2}. These protocols can facilitate a deeper engagement with the knowledge and customary governance systems of Indigenous Peoples and local communities within, rights-based frameworks and in accordance with national legislation, benefitting both good quality of life and effective management of biological invasions *(established but incomplete)* {6.4.3.2}. Social research can help to better inform management and policy and build trust between sectors of society *(established but incomplete)* {6.4.4, 6.6.1.4}. Social research can also provide valuable information on how best to share knowledge and on invasive alien species status and trends on land managed by stakeholders and Indigenous Peoples and local communities *(well established)* {6.4.1, 6.6.1.5, 6.2, 6.4}.

8 The current understanding of the biological invasion process, which includes extensive information on many of the currently most impactful species and well-established principles for prevention and control, is adequate for guiding effective action on invasive alien species *(well established)* {6.1.2, 6.1.3, 6.2.3, 6.2.4}. The complexity and uncertainty of social, economic and environmental costs and benefits of invasive alien species is broadly acknowledged *(well established)* {6.2.2} and is a central obstacle to predicting biological invasions, including the outcomes of invasion, necessitating a precautionary approach *(well established)* {6.1.2, 6.2.2, 6.3.1.2}. Nonetheless, the key aspects of this complexity are understood, including the multiple sectors and stakeholders that contribute to and are affected by invasive alien species *(well established)* {6.2.3}. Which sectors and stakeholders are involved is context dependant and their specific roles depend on the invasive alien species involved and the ecosystems affected *(well established)* {6.2.3.3, 6.3.1.1, 6.4.1, 6.7.2.5}. A further dimension of complexity that can be considered in the governance and management of biological invasions is the interaction between invasive alien species and other key drivers of change in nature, including climate change, pollution and land-use change *(well established)* {6.3.1.3}. Given the strong interactions between these drivers, considering all forms of global environmental change can yield benefits for effective environmental governance *(well established)* {6.2.3.3, 6.3.1.3, 6.7.2.2}. Despite these complexities and the uncertainty that can affect decision-making, scientific and technical solutions exist for designing efficient and effective options to deal with biological invasions {6.2.3}, and for supplying the information needed to support policy and management decisions *(well established)* {6.6.2}. Strategic investment in research to keep data and information up to date and to fill key gaps will improve the efficiency and effectiveness of management of biological invasions *(well established)* {6.6.1} **(Table 6.10)**.

9 An integrated governance approach that connects and combines key strategic interventions and creates robust governance system properties can bring about context-relevant transformative change for the effective prevention and control of invasive alien species *(established but incomplete)* {6.2.4, 6.7.1} (Figure 6.21). Positive transformation can be achieved by (a) strengthening the connectivity within the invasion governance system, using information technology and international partnerships {6.6.2.7, 6.7.2.6}; (b) developing stronger and broader global regulatory instruments to address invasions threats {6.3.1, 6.7.2.3} as well as higher visibility of biological invasions in national legislations and environmental actions plans {6.2.4.2, 6.3.2, 6.7.2.1}; (c) engaging all relevant sectors including health, environment, agriculture, fisheries and forestry, and all relevant stakeholders including the private sector, the general public and Indigenous Peoples and local communities{6.2.3.3, 6.3.1.1, 6.4.2.2, 6.7.2.4, 6.7.2.5}; and (d) supporting innovative science and environmentally sound technologies for solutions-focused approaches {6.3.3.4, 6.7.2.6}. Governance that is responsive to changes in biological invasion risk and management contexts, focuses on effective implementation, sustains investment and commitment to goals, and is equitable and inclusive across both those affected and responsible, can bring about a step change in the prevention and control of invasive alien species *(well established)* {6.2.4, 6.7.3}.

6.1 INTRODUCTION AND OUTLINE

This chapter evaluates past and possible future governance models and challenges, policy instruments and support tools, collectively called response options (**Glossary**). These response options are aimed at managing biological invasions (**Chapter 1**, **Figure 1.1**; **Glossary**) to reduce their impacts on nature, nature's contributions to people and good quality of life (**Box 6.1**; **Glossary**). Governance models (**section 6.2**) target specific components of the socioecological system, are complimentary and tend to draw on specific sets of policy instruments, tools and methods. Policy instruments (**sections 6.3** and **6.5**) are the set of options (means or mechanisms) used at any scale by individuals or organizations for building or strengthening international, national and local efforts to manage biological invasions. Policy support tools and methods (**section 6.6**) are approaches that can inform, assist and enhance relevant decisions, policy-making and implementation at the local, national, regional and international levels, to better prevent and control these species and their impacts (**Glossary**).

Multiple international organizations and programmes have highlighted the roles of governance models **(Table 6.1)**, policy instruments and policy support tools and methods **(Table 6.1)** as means to achieve international policy targets for preventing and controlling invasive alien species and managing biological invasions (**Chapter 1**, **Box 1.1**). They include the Convention on Biological Diversity (CBD), the International Union for Conservation of Nature (IUCN)

Box 6 1 **Rationale of the chapter.**

This chapter builds on previous chapters of the IPBES invasive alien species assessment to present response options for improving and strengthening the governance for biological invasions. The chapter explores governance models and policy instruments (legal, regulatory and incentive-based) and support tools available for multilateral efforts and national strategies to prevent and control invasive alien species. Together, the integration of these strategic actions could lead to positive transformative change (**Glossary**).

Guiding questions:

- What are the challenges facing biological invasions governance?
- What are the current gaps, overlaps and inconsistencies in existing legal and regulatory instruments focused on biological invasions management (**Glossary**)?
- Which decision and engagement tools can be used to manage biological invasions?
- What economic instruments can be implemented to fund or promote the various prevention, eradication, containment, mitigation, restoration and ecosystem-based management options (**Glossary**)?
- How to develop information systems (**Glossary**) to help design, implement and monitor response options to the biological invasions problem?

Keywords:

Governance, policy instruments, community engagement, integrated governance, goals and targets, multilateral coordination, implementation strategies, coherent policy regimes, open data, information systems.

Table 6 1 **Array of possible governance and policy response options for managing biological invasions.**

Possible response options that can be used to (i) prevent or mitigate the main drivers responsible for biological invasions and (ii) prevent the impacts of invasive alien species on nature and society. The response options include models of governance, categories of policy instruments and families of support tools and methods (IPBES, 2019a).

Governance Models	Categories of Policy instrument	Families of support tools and methods (main governance model/s in brackets)
A. Hierarchical	Legal and regulatory	Assembling data and knowledge (B)
B. Scientific-technical	Economic and financial	Assessment and evaluation (B)
C. Governing strategic behaviour	Rights-based and customary norms	Public discussion, involvement and participatory process (D)
D. Adaptive-collaborative	Social and cultural instruments	Selection and design of policy instruments (A, B)
		Implementation, outreach and enforcement (A, C)
		Training and capacity-building (B, D)
		Social learning and innovation (D)

Invasive Species Specialist Group (ISSG), the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO), the International Plant Protection Convention (IPPC), the World Organisation for Animal Health (WOAH, founded as OIE), the World Trade Organization (WTO), the International Maritime Organization (IMO), the World Bank and the Centre for Agriculture and Biosciences International (CABI). Many of these organizations participate in the Inter-agency Liaison Group on Invasive Species established by the Executive Secretary of the CBD.

Guided by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework (**Chapter 1**, **section 1.6.1**; **Figure 6.1**), possible options to prevent and manage biological invasions outlined in this chapter respond to direct and indirect drivers of change responsible for biological invasions, and to the possible impacts of invasive alien species on nature, nature's contributions to people and good quality of life. **Section 6.2** presents options to strengthen the governance systems within which policy instruments and support tools for biological invasions are implemented. These include options for enhancing the coverage and strategic nature of biological invasions governance, dealing with multiple levels and sectors of society, as well as enhancing governance capabilities. **Section 6.3** evaluates the limitations of and opportunities for the current array of legal and regulatory frameworks, highlighting the need for strategies that bridge and coordinate across sectors, geopolitical units and stages of the biological invasion process. **Section 6.4** lays out the role of widespread engagement and the context and reasons for the broad and specific inclusion of stakeholders and Indigenous Peoples and local communities. This section examines the range of approaches for coordination and collaboration and shows how stakeholder and Indigenous Peoples and local communities' engagement can improve biological invasions governance. **Section 6.5** outlines financial and economic policy options that provide incentives for international organizations, governments, financial institutions and individuals to invest in invasive alien species prevention, containment, mitigation, or eradication (**Glossary**). This section assesses the role of tariffs, cost-sharing and penalty systems as deterrents to invasive alien species (**Glossary**) introduction and spread and as a financing alternative. This section also presents support tools for analysing the costs and benefits of invasive alien species. **Section 6.6** specifies options for generating and maintaining the information and knowledge needed to govern and manage biological invasions. This section identifies knowledge gaps and options for access to the information needed for the creation of early warning systems, for forecasting the spread and impact of invasive alien species and for assessing management effectiveness. Information needs for the purpose of developing and reporting on the effectiveness of policy instruments are also described. Finally, **section 6.7** summarizes the key governance and policy challenges and opportunities for sustainable biological

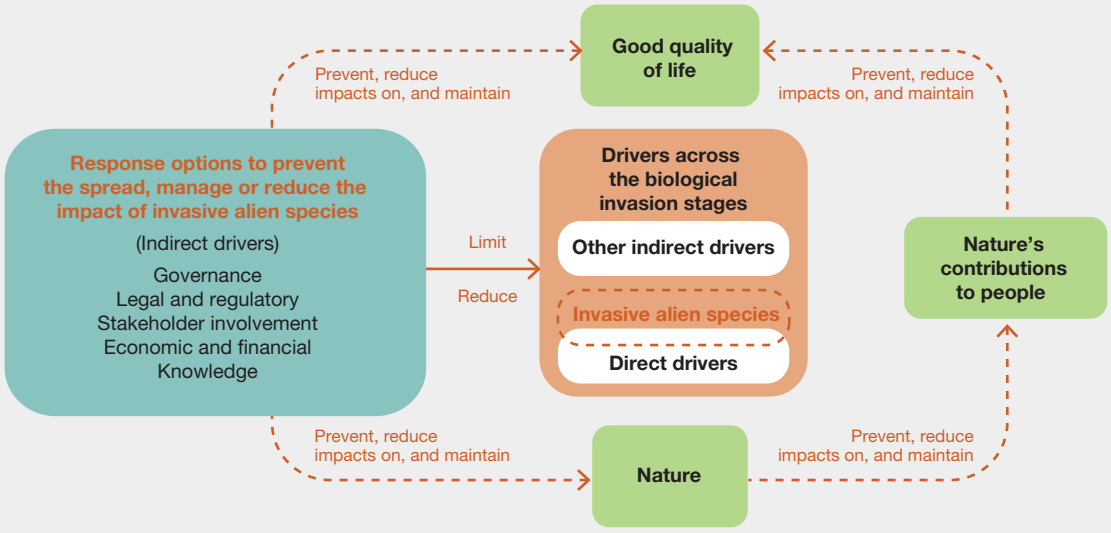

Figure 6 1 **Framework for governance and policy response options and how they relate to nature, nature's contributions to people and good quality of life.**

Simplification of the IPBES conceptual framework that describes the array of response options (left box) to limit the drivers facilitating biological invasion and the spread of invasive alien species (middle box) and mitigate their negative impacts on good quality of life (surrounding boxes connected by dashed arrows). Modified from S. Díaz *et al.* (2015), https://doi.org/10.1016/j.cosust.2014.11.002, under license CC BY-NC-SA 3.0.

invasion management that emerge from the assessment. This section outlines the set of strategic actions and governance system properties that can jointly construct an integrated approach to the governance for biological invasions that can bring about a step change in progress to achieving related policy and management goals.

6.1.1 Risks and opportunities

The IPBES invasive alien species assessment and previous IPBES assessments (as outlined in **Table 6.2**) identify risks and opportunities that provide the basis for determining future options and strategies to prevent and mitigate the impacts of invasive alien species on nature, nature's contributions to people and good quality of life **(Figure 6.1)**. These risks and opportunities can be categorized into ten groups **(Table 6.2)** and lay the foundation for the strategic identification of governance policy instruments and options. These risks and opportunities also reveal where adaptation is the most feasible option, when eradication or adequate management is no longer feasible, and when such an adaptive response could lead to a positive system transformation.

Table 6 2 **Risks (hazard or impact taking place) and opportunities (circumstances that make it possible to act) for managing biological invasions as defined in the IPBES invasive alien species assessment and other IPBES assessments.**

The risks and opportunities showcased provide an overview of the main governance challenges, policy instruments and knowledge needs that are highlighted in this chapter to effectively manage biological invasions. The relevant sections within the IPBES invasive alien species assessment and other IPBES assessments are highlighted for each of the points raised.

Risks and/or opportunity	Description (relevant chapter sections of this/previous IPBES assessments)
Information disparity	• Geographic, taxonomic, data access and publication biases (**Chapter 6**, **section 6.6.1**; **Chapter 4**, **section 4.7.2**; IPBES, 2018a) • Comparatively limited knowledge of invasive alien species impacts on fisheries, coral reefs and marine ecosystem functioning (**Glossary**; **Chapter 4**, **section 4.7.2**)
Information uncertainty	• Uncertainty about management cost, efficacy, limitations, success, collaborations and adaptation (**Chapter 5**; IPBES, 2018b) • Uncertainty about dispersal pathways, transboundary and regional collaboration (**Glossary**; **Chapter 3**, **section 3.6.1**; IPBES, 2018b) • Uncertainty about the impacts of novel assemblages/ecosystems emerging due to invasive alien species (**Chapter 4**)
Framing biological invasions in terms of their interactions with other environmental problems	• Inadequate integration of biological invasion problems in policies and management interventions aimed at addressing other environmental problems such as land degradation or climate change (**sections 6.3.1** and **6.7**; IPBES, 2016, 2018d)
Policies as drivers facilitating biological invasions	• Lack of coordination of policies on environment, infrastructure, health, agriculture, forests, environment, nutrition and biological invasion management can catalyse invasive alien species spread (**section 6.3.1**; IPBES, 2018d) • Inefficient policies on climate change, pollution, human population, land-use change, pet and wildlife trade, afforestation, horticulture and health had severe consequences on spread and impacts of invasive alien species (**section 6.3**) • Lack of coordination between policies of different sectors (**section 6.3.1**) and between national and regional regulations (**sections 6.3.2** and **6.3.3**)
Impact disparity	• Management of biological invasions is particularly difficult when they simultaneously have both serious negative environmental impacts and benefits for good quality of life or are characterized by value conflicts (**Chapters 4** and **5**) • Use of potentially invasive alien species in programmes aimed to ensure food security or promote economic development (**section 6.3**)
Technological advancement	• Absence of early detection systems and rapid response actions for prevention and eradication of invasive alien species (**section 6.6**) • Lack of monitoring (**Glossary**) programmes to track the effectiveness of responses and progress in managing biological invasions (**section 6.2**) • Lack of inter-operable and standardized databases (**section 6.6**; IPBES, 2018c, 2019a)
Economic synergies	• Conflict of interest in international regulatory frameworks with a direct or indirect focus on preventing invasive alien species introductions (**sections 6.3** and **6.5**) • Difficulties with assessing the collective investment in prevention and control of invasive alien species, how adequate they are, and costs avoided as a result (**section 6.1**)

Table 6 2

Risks and/or opportunity	Description (relevant chapter sections of this/previous IPBES assessments)
Societal response	• Lack of public support, financial resources and awareness of risks associated with invasive alien species among all stakeholders (**sections 6.4** and **6.5**, IPBES, 2018a, 2019a) • Absence of institutions that coordinate and provide oversight on invasive alien species prevention, control and mitigation strategies, and promote the flow of information (**sections 6.3** and **6.7**)
Engagement with Indigenous Peoples and local communities	• Engaging with stakeholders and Indigenous Peoples and local communities (**section 6.4**) • Lack of integration of stakeholder and Indigenous and local knowledge (**Glossary**) and limited engagement of stakeholders and Indigenous Peoples and local communities in decision-making for biological invasions (**section 6.4**)
Gaps in knowledge of governance	• Lack of information about the success of governance in management interventions (**section 6.2**) • Limited dedicated interdisciplinary research on the governance for biological invasions in an environmental governance context (**section 6.2**)

6.1.2 Progress towards international and national goals and targets for invasive alien species

The CBD is currently the most encompassing and directly relevant global environmental governance mechanism for biological invasions. It has the following three objectives: the conservation of biological diversity; the sustainable use of the components of biological diversity; and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources (**Figure 6.1**, **section 6.1.2**). The Conference of the Parties (COP) to the CBD has also specifically recognized that invasive alien species represent one of the primary threats to biodiversity, especially in geographically and evolutionary isolated ecosystems, such as small island developing States (SIDS). As early as 2002, the CBD COP adopted a series of Guiding Principles for improving the governance for biological invasions **(Table 6.3)**. These Guiding Principles remain highly relevant and provide a list of options to accelerate and sustain progress on invasive alien species and their control. The responsibilities of Parties to the CBD are therefore longstanding, and gaps and shortcomings in the governance for biological invasions over the last several decades (**section 6.1.3**) have meant that actions have not been sufficient to stop their spread (**Chapter 2**).

Under the recent Kunming-Montreal Global Biodiversity Framework (CBD, 2022a), the invasive alien species target (Target 6) encompasses eliminating, reducing and mitigating impacts through pathway management (**Glossary**), prevention and with a focus on priority species and priority sites (**Chapter 1**, **Box 1.1**). With the addition of some new elements Target 6 reinforces the key elements of the previous Aichi Biodiversity Target 9, based on which current progress has been evaluated. Assessment of the progress towards meeting Aichi Biodiversity Target 9 (invasive alien species prevented and controlled) concluded that, while increases in the adoption of related policy was encouraging, there was still a considerable gap between the development and adoption of invasive alien species policy, and implementation at national levels (Secretariat of the CBD, 2020; **Table 6.4**).

The fifth edition of the Global Biodiversity Outlook also indicated that there has been no reduction in the pressure from invasive alien species on biodiversity, ecosystems and society (Secretariat of the CBD, 2020). Factors identified as underlying the imperfect achievement of Aichi Biodiversity Target 9 included: inadequate policy implementation due to limited capacity and resourcing of relevant governmental agencies; lack of coherence across multiple, relevant policies; and the fact that policy adoption does not equate directly to management effectiveness. This Global Biodiversity Outlook report further pointed out the lack of research and data on biological invasion policy effectiveness at a global scale (Secretariat of the CBD, 2020). Subsequent studies have also identified poor governance as a factor limiting national-level progress to achieving other Aichi Biodiversity Targets (Buchanan *et al.,* 2020).

The Sustainable Development Goals (SDGs) also include a target for invasive alien species (Target 15.8; **Chapter 1**, **Box 1.1**) closely related to Aichi Target 9 of the Strategic Plan for Biodiversity 2011-2020. This target aims to track progress in the commitment by countries to relevant multilateral agreements, and the proportion of countries with national strategies, legislation and policy for invasive alien species. However, the indicators that were selected to track progress of Target 15.8 of the 2030 Agenda for Sustainable Development also included for the first time an "input response" element (i.e., the extent to which the measures identified are resourced; **section 6.2.1**).

Table 6 3 **The 15 Guiding Principles for the prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species.**

The text associated with these principles is not provided in full here – abbreviated notes are shown where particularly relevant to invasive alien species governance as discussed in **section 6.2** (**Chapter 1**, **section 1.3.1**). Source: CBD (2002).

No.	Guiding Principle
A. GENERAL	
1	**Precautionary approach:** efforts to identify and prevent unintentional introductions as well as decisions concerning intentional introductions should be based on the precautionary approach as described in Principle 15 of the 1992 Rio Declaration.
2	**Three-stage hierarchical approach:** prevention is the top priority; followed by early detection, rapid response and eradication; and then containment, long-term control measures and examination of the benefits and costs.
3	**Ecosystem approach:** as described in decision V/6 of the Conference of the Parties.
4	**The role of States:** States should recognize the risk that activities within their jurisdiction or control may pose to other states and should take appropriate individual and cooperative actions to minimize that risk, including making information on the identity of invasive alien species available to other states.
5	**Research and monitoring:** Research on an invasive alien species should focus on the history and ecology of invasions, the biological characteristics of the invasive alien species, and the associated impacts. Monitoring should involve multiple sectors and include both targeted and general surveys.
6	**Education and public awareness:** Promote education and public awareness of the causes of invasion and the risks associated with the introduction of alien species.
B. PREVENTION	
7	**Border control and quarantine measures:** Putting in place appropriate measures to control introductions of invasive alien species based on risk analysis of threats and potential pathways of entry.
8	**Exchange of information:** CBD Parties should assist in developing an inventory and synthesis of relevant databases, and developing information systems and an interoperable distributed network of databases for compilation and dissemination of information on alien species. The Parties should provide all relevant information on their specific import requirements for alien species and make this information available to other States.
9	**Cooperation, including capacity-building:** Cooperation should be based on programmes developed to share information as well as cooperative research and funding efforts. Capacity-building may involve technology transfer and the development of training programmes, especially for countries that lack expertise and resources.
C. INTRODUCTION OF SPECIES	
10	**Intentional introduction:** No first-time intentional introduction or subsequent introductions of an alien species already invasive or potentially invasive within a country should take place without prior authorization from a competent authority of the recipient state(s).
11	**Unintentional introductions:** Provisions to address unintentional introductions need to be set in place.
D. MITIGATION OF IMPACTS	
12-15	(full text not provided here) Including mitigation of impacts (no.12), eradication (no.13), containment (no.14) and control (no.15) (**Chapter 5**).

By comparison, multilateral instruments or organizations such as the IPPC and WOAH have been widely successful in developing and implementing instruments to mitigate the risks of invasive alien species considered to be pests or to affect animal health. There are over 40 adopted international standards for phytosanitary measures (ISPMs, developed by IPPC),[2] 31 Diagnostic Protocols, and 39 Phytosanitary Treatments aimed to protect the environment, forests and biodiversity while also facilitating economic and trade development. The standards and codes developed by the IPPC and WOAH have provided a foundation for multilateral collaboration in managing the risks posed by invasive alien species.

2. https://www.ippc.int/en/core-activities/standards-setting/ispms/

Table 6 4 **Progress against invasive alien species policy goals and targets.**

Indicator category	Indicator[3]	Elements of Aichi Biodiversity Target (AT) 9 and SDG Target 15.8	Global progress against Target or Goal
Driver	Trends (**Glossary**) in pathways of introduction and spread	Measures are in place to manage pathways to prevent introduction and establishment (AT); Introduce measures to prevent the introduction of invasive alien species (SDG)	Progress has been made, but at an insufficient rate. This target has not been achieved (high confidence; (Secretariat of the CBD, 2014, 2020). Major pathways are not efficiently controlled at a global scale (Secretariat of the CBD, 2014), but major advancements have been made in the context of shipping (in particular, an agreement to prevent biological invasions *via* ballast water).
		Pathways identified and prioritized (AT 9.2)	Major pathways have been identified (Faulkner *et al.,* 2020; IUCN, 2017; Saul *et al.,* 2017; Secretariat of the CBD, 2014). However, the pathways of introduction of more than a third of introduction events are unknown (McGrannachan *et al.,* 2021).
Pressure	Trends in numbers of invasive alien species and their impacts	None	The number of documented, new introductions of alien species continues to increase (Seebens *et al.* 2017). Progress towards target has been made, but at an insufficient rate (Secretariat of the CBD, 2014).
		Invasive alien species are identified and prioritized (AT 9.1)	Measures have been taken in many countries to develop checklists of invasive alien species (Secretariat of the CBD, 2014, 2020). Target partially achieved.
State	Trends, mechanisms and severity of invasive alien species impacts	Introduce measures to significantly reduce the impact of invasive alien species (SDG)	A negative trend in the conservation status of species threatened by invasive alien species in the Red List Index (McGeoch *et al.,* 2010) suggests that this target has not been achieved. Overall, there has not been an improvement in conservation status of species threatened by invasive alien species, although some progress has been made for some species and for species on islands (CBD, 2020b; Secretariat of the CBD, 2014).
Response Input	Trends in the allocation of resources towards the prevention or control of invasive alien species	Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species (SDG)	Of the 195 countries party to the CBD, almost half have no national budget and no funding *via* global mechanisms for invasive alien species prevention and control activities (Pagad *et al.,* 2020).
Process	Trends in establishment and national adoption of international agreements relevant to the prevention and control of invasive alien species	Trends in policy responses, legislation and management plans to control and prevent spread of invasive alien species (Pagad *et al.* 2020)	Between 30 and 90 per cent of all countries are signatory to the nine multilateral agreements relevant to the prevention or control of invasive alien species, including the CBD, with most countries' signatory to the World Heritage Convention, IPPC and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; 2% increase since 2010; Pagad *et al.,* 2020). Likewise, most of the world shipping tonnage (over 91%) is under regulation under the International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWM Convention; IMO, 2022). Trends in adoption overall are positive since 1970 (Pagad *et al.,* 2020).
	Trends in numbers of countries with national legislation and other policy measures relevant to the prevention and/or control of invasive alien species	Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species (SDG)	Only 10% of reporting parties have national targets of similar scope and ambition to Aichi Biodiversity Target 9 and are on track to meet them (CBD, 2020b). Party self-assessment is variable as assessed against their own national targets (Secretariat of the CBD, 2020). Most countries (190) party to the CBD have some form of national legislation relevant to invasive alien species; 17% of these are specifically focussed on invasive alien species (Pagad *et al.,* 2020). 39% of countries have developed a national invasive species strategy and action plan (NISSAP; Pagad *et al.,* 2020). 10% of countries rely entirely on international funding for invasive alien species prevention and control activities (Pagad *et al.,* 2020). Of the countries party to the CBD (195), 80% have invasive alien species targets in their national biodiversity strategies and action plans (NBSAPs), 74% are aligned with Aichi Biodiversity Target 9 (Pagad *et al.,* 2020).
Output	Trends in the prevention of invasive alien species	Measures are in place to manage pathways to prevent introduction and establishment; Priority species are controlled or eradicated (AT 9.4); Introduce measures to control or eradicate priority invasive alien species (SDG)	There has been no significant overall progress towards this target (Secretariat of the CBD, 2014). Some measures have been put in place but are not sufficient to prevent the continuing increase in invasive alien species.

Table 6 4

Indicator category	Indicator[3]	Elements of Aichi Biodiversity Target (AT) 9 and SDG Target 15.8	Global progress against Target or Goal
Output	Growth in information relevant to informing policy on invasive alien species prevention and control	none	In progress
Outcome	Trends in successful control and eradications of invasive alien species	Priority species are eradicated (AT 9.3)	Progress towards target, but at an insufficient rate (Secretariat of the CBD, 2020). Some control and eradication, but data limited. Progress has been made, but Target has not been achieved.25% of invasive alien species mammal eradications on islands have occurred since 2010 (Secretariat of the CBD, 2014, 2020).
		Priority species are controlled (AT 9.3)	Data limited (Secretariat of the CBD, 2020). Target unlikely to have been achieved.

3. The indicator here is expressed in an inclusive general form, encompassing relevant alternative formulations of closely related indicators.

6.1.3 Specific progress towards governance-related invasive alien species goals

Response plans and monitoring for invasive alien species

In general, goals specific to societal "responses" to biological invasions are very poorly developed, as is the availability of data on response plans and response monitoring (**section 6.6.3**; Vicente *et al.,* 2021). Nonetheless, some components of existing invasion targets and associated indicators fall into this "response" category, and these are highly relevant to the governance for biological invasions at global and national scales. These include the existence and uptake of multilateral agreements and national legislation relevant to the prevention and control of invasive alien species, and resourcing of invasive alien species prevention and control activities (McGeoch *et al.,* 2010; Pagad *et al.,* 2020; **section 6.6.3**).

Multilateral agreements

Monitoring of the response targets that do exist (**section 6.6.3**) shows that there has been a small increase in the number of countries that are signatories of seven relevant multilateral agreements in the last decade, and country adoption ranges from about 60 per cent to 98 per cent across these agreements (**Figure 6.2**; Pagad *et al.,* 2020). Of these, IPPC and WOAH have been critical instruments for preventing the introduction of invasive alien species and defining the roles of authorities working on biosecurity (**Glossary**) to prevent introductions of invasive alien species. Likewise, the eighth, and most recent, agreement – the BWM Convention – has reached a country signatory level of 33 per cent since it was established in 2004 (**Figure 6.2**; **Chapter 5**, **section 5.5.1**), although it was ratified only in 2017. The over 60 country signatories to this convention are responsible for 91 per cent of the world's shipping tonnage (IMO, 2022), making it a potentially powerful instrument for preventing invasive alien species; interestingly, this is the only multilateral treaty adopted specifically to prevent the spread of invasive alien species.

National legislation

The development and adoption of relevant national legislation is split across agricultural and environmental sectors, and in some cases also split across industries involving plants and those involving animals **(Figure 6.3)**. Only 17 per cent of countries have invasive alien species-dedicated national legislation (Pagad *et al.,* 2020), whereas an estimated 69 per cent have invasive alien species-specific legislation as part of legislation in other sectors (in addition to plant and animal health legislation that is broadly relevant to invasive alien species; Pagad *et al.,* 2020).

Overview of progress

The development of action plans for invasive alien species by CBD parties can help them achieve biological invasion-relevant goals and targets, such as occurred under the previous Aichi Target 9 of the 2011-2010 Strategic Plan (CBD, 2020). However, across the elements of Aichi Biodiversity Target 9 and related Target 15.8 of the 2030 Agenda for Sustainable Development, limited progress was made over the decade to successfully prevent, control

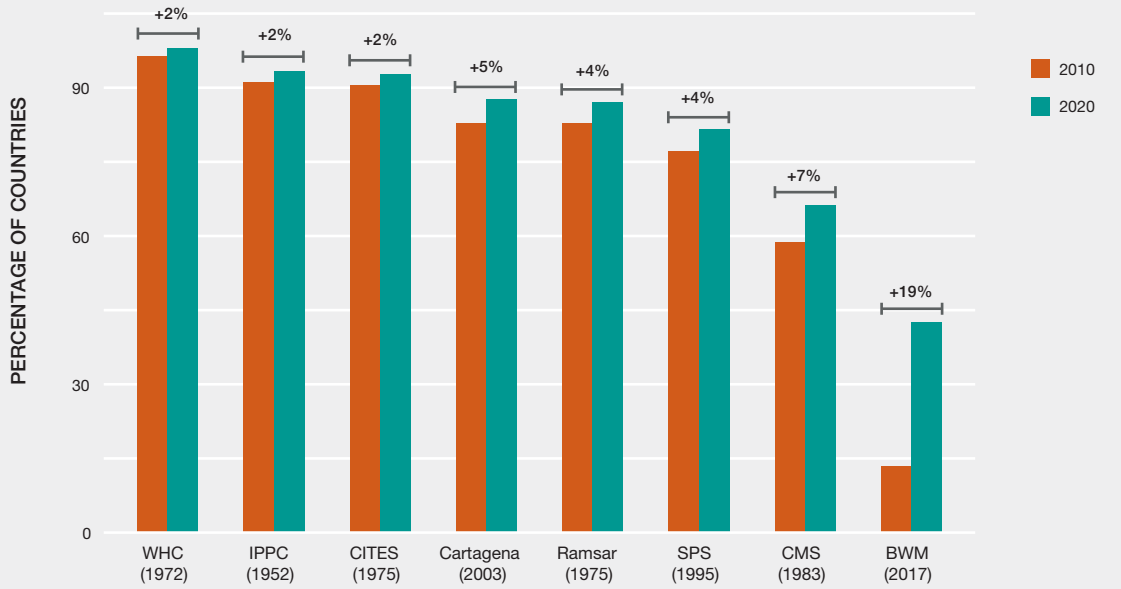

Figure 6 2 **Percentage of countries (y axis) signatory to eight multilateral agreements relevant to the prevention and control of invasive alien species (x axis).**

Data is shown for 2010 (left bars; n = 192) and 2020 (right bars; n = 195), with % increase since 2010 (shown above), signatory countries to eight multilateral agreements relevant to the prevention and control of invasive alien species. Only countries party to the CBD at the time of reporting were considered in the analysis. The eight multilateral agreements (year of establishment below acronym in figure) analysed were the Cartagena Protocol on Biosafety to the CBD (CBD, 2000), the IPPC (IPPC, 1952), the Agreement on the Application of Sanitary and Phytosanitary Measures of the WTO (WTO SPS; WTO, 1995), CITES (CITES, 1975), the Convention on Wetlands of International Importance (Ramsar) (Secretariat of Convention on Wetlands, 1971), the Convention on the Conservation of Migratory Species of Wild Animals (CMS) (CMS, 1979), the World Heritage Convention (WHC) (UNESCO, 2017) and the BWM Convention) (IMO, 2004). The WOAH (WOAH, 2011) has a high level of uptake (93%) and showed no change between 2010 and 2020 and is therefore not included in the figure. Source: Pagad *et al.* (2020), https://opal.latrobe.edu.au/articles/report/International_Adoption_of_Invasive_Alien_Species_Policy/13065158, under license CC BY 4.0.

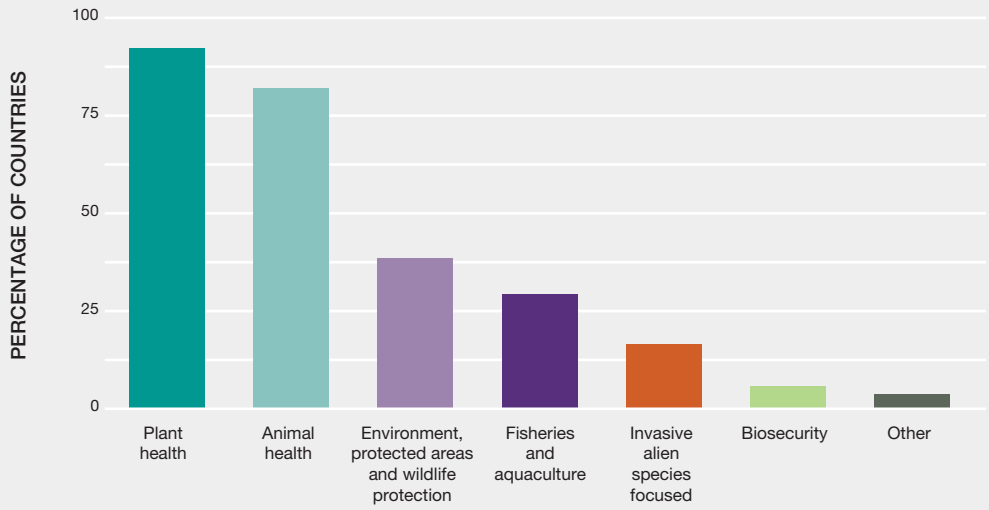

Figure 6 3 **Adoption of national legislation relevant to the prevention and/or control of invasive alien species.**

Data is shown for 195 countries reporting to the CBD. The percentage of countries (y axis) with national legislation in invasive alien species-relevant sectors (x axis) shown. Source: Pagad *et al.* (2020), https://opal.latrobe.edu.au/articles/report/International_Adoption_of_Invasive_Alien_Species_Policy/13065158, under license CC BY 4.0.

and reduce the impacts of invasive alien species (**section 6.1.2**; **Table 6.4**). Most countries (about 196 countries; Pagad *et al.,* 2022) now have checklists of introduced and invasive alien species, but the documented numbers of new introductions continue to increase (**Chapter 2**; Seebens *et al.,* 2017). The overall conservation status of species threatened by invasive alien species (Blackburn *et al.,* 2019) continues to worsen, many countries have little to no funding for invasive alien species activities (Blackburn *et al.,* 2019; **section 6.1.2**), and most national invasive alien species targets lacked ambition relative to Aichi Target 9 **(Table 6.4)**. Legislative and other policy instruments for invasive alien species are highly variable across countries and across sectors within countries (Pagad *et al.,* 2020; **section 6.1.2**). Data available for assessing the management of pathways of introduction of invasive alien species and of alien species (**Chapter 5**, **section 5.3.1**), and the effectiveness of this management, are inadequate and largely unavailable **(Table 6.4)**.

Resourcing

Estimates of the financial cost of biological invasions to countries vary widely, depending on the data source, location and evaluation method used (Diagne *et al.,* 2020). Based on country-sourced data (Pagad *et al.,* 2020), estimates of country investment in the prevention and control of invasive alien species (**section 6.5**) show that close to half of countries allocate no funds, with most such countries concentrated in Africa (**Figure 6.4** and **Figure 6.5**). Indeed, Africa depends most heavily on globally-sourced funding for the prevention and control of invasive alien species **(Figure 6.5)** and needs additional resources to support policy development and reporting (Egoh *et al.,* 2020). In the other IPBES regions, funds are allocated through a mix of national and international sources **(Figure 6.5)**. Europe and Central Asia have the highest rates of nationally derived funding. However, even where relevant legislation has been adopted, countries face significant resource shortages (Outhwaite, 2018). It is important to note that in these indicators, investment in resourcing of biological invasions policy and management implementation is different from the realized "cost" of invasive alien species measured as damage or loss from invasive alien species and expenditure on management (Diagne *et al.,* 2020).

In summary, globally representative, country-relevant data on the governance for biological invasions and related policy instruments show generally high levels of compliance with multilateral agreements. Such agreements do contribute to prevention and control of invasive alien species and stimulate the existence of many different national instruments, though in most countries these

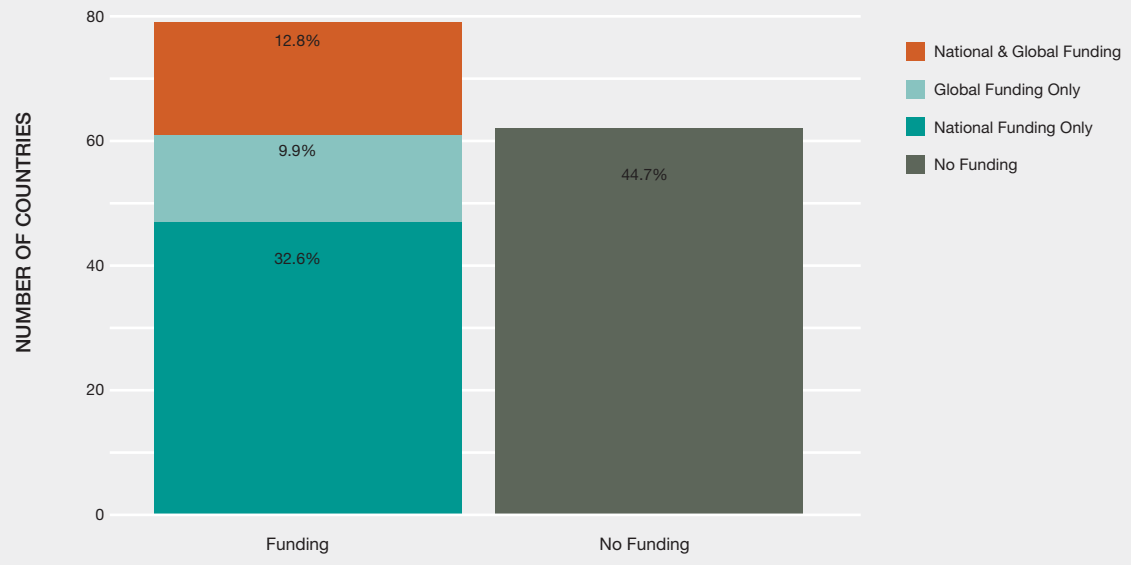

Figure 6 4 **Allocation of financial resources to the prevention and control of invasive alien species, including both national and global financial mechanisms.**

Source: Pagad *et al.* (2020), https://opal.latrobe.edu.au/articles/report/International_Adoption_of_Invasive_Alien_Species_Policy/13065158, under license CC BY 4.0.

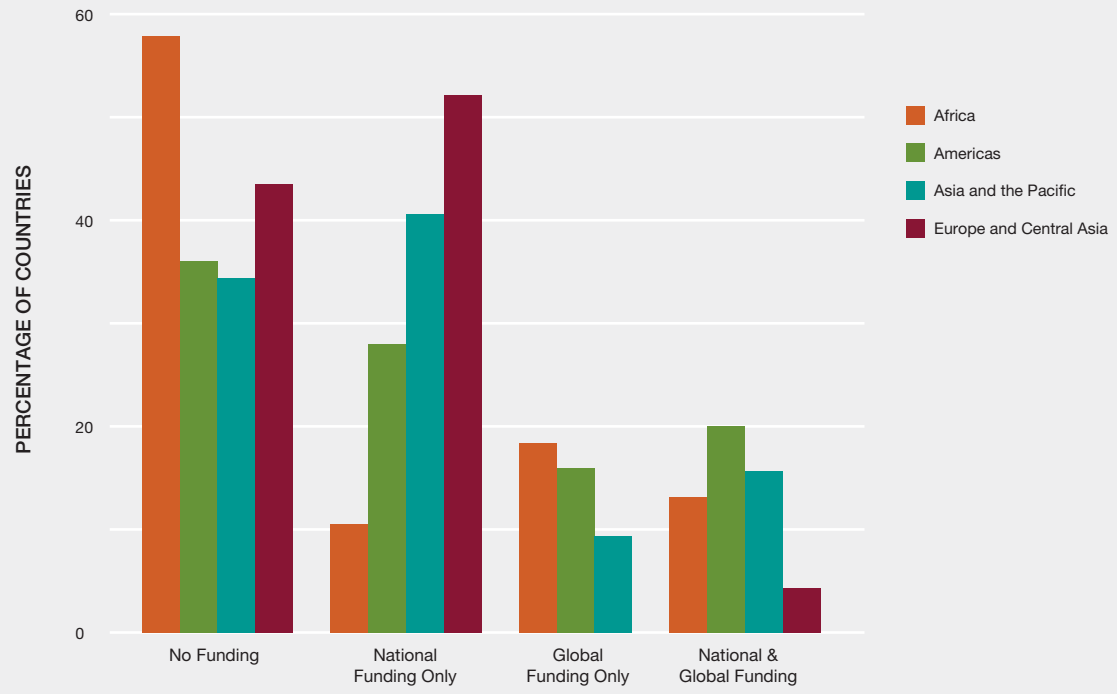

Figure 6 5 **Percentage of countries (y axis) per IPBES region that have accessed different funding sources (x axis) for invasive alien species prevention and control.**

Africa: n = 38, Americas: n = 25, Asia and the Pacific: n = 32, Europe and Central Asia: n = 46. Source: Pagad *et al.* (2020), https://opal.latrobe.edu.au/articles/report/International_Adoption_of_Invasive_Alien_Species_Policy/13065158, under license CC BY 4.0.

instruments are siloed within industry sectors **(Figure 6.3)**, most of which are not dedicated to invasive alien species prevention and control. A thorough analysis of national legislative instruments for biological invasions is still lacking (perpetuating the situation identified mid-term in the Strategic Plan for Biodiversity 2011-2020), as are assessments of the effectiveness of invasive alien species legislation (Leadley *et al.,* 2014).

Although evidence for progress in establishing and advancing effective governance for biological invasions is patchy and incomplete, the weight of evidence points to a failure to adequately resource, prevent and control invasive alien species (throughout this assessment and **section 6.6.3**). While it is not possible to establish how much worse the situation would be in the absence of the substantial collective investment made to date to prevent and control invasive alien species (**Chapter 5**, **section 5.5.7**), it can be inferred that governance approaches and governance systems for biological invasions have been inadequate. Strengthening related governance provides an overarching option for improving the prevention and control of invasive alien species and making faster progress toward achieving multilateral goals and targets (Buchanan *et al.,* 2020).

6.2 GOVERNANCE RESPONSE OPTIONS

This section provides context for assessing governance options for biological invasions. It aims to clarify the understanding of the governance system within which a policy instrument or policy support tool for biological invasions is being implemented **(Box 6.2)**. "Good governance is an enabling condition for policy implementation, distributing the resulting positive impacts evenly across society" (IPBES, 2019b). This section identifies governance considerations from invasive alien species-specific literature and contextualizes these within environmental governance more broadly. A key finding is that there is little dedicated interdisciplinary research on the governance for biological invasions in an environmental governance context.

The concept of governance is defined and used in several ways. This assessment uses the formulation and rationale of Gilek *et al.* (2016):

> "Governance includes both structures – such as policy contexts, existing power relations among key actors,

Box 6 2 **Governance for biological invasions.**

Governance encompasses the norms, rules, laws, values, expectations, relationships and structures that affect or guide the behaviour of individuals and institutions, public and private. In the context of biological invasions, governance is aimed at the specific public purpose of preventing and reducing the spread and preventing the harm, caused by invasive alien species (Andonova & Mitchell, 2010; M. S. Reed & Curzon, 2015). The governance for biological invasions therefore encompasses formalized arrangements such as national strategy and legislation, as well as informal decision-making processes involving the range of effecting and affected stakeholders (**section 1.5.1** in **Chapter 1** for more information on stakeholder groups, Reed & Curzon, 2015). A key feature of governance for biological invasions is that it is a continuous, cooperative process that accommodates diverse and conflicting interests to enable action (Riley, 2012).

> regulatory frameworks and organizational forms of decision-making, reflexivity and participation – and processes. Processes comprise aspects such as the evolution of institutions and interactions between, for example, science and policy, as well as communication and interaction among policymakers, scientists, and other stakeholders. Processes also include the development of strategies, framings, communication, and learning."

Strong governance can help to address the problem of invasive alien species, as it enables the legislation, regulations, cooperation, participation and monitoring of actions to mitigate key drivers (T. Evans *et al.,* 2018).

6.2.1 The theory of change and indicator frameworks for improving implementation

The Driver-Pressure-State-Response (DPSR) model, sometimes including impacts (DPSIR; OECD, 2003), is a strategic framework used for reporting on global and national progress toward meeting goals and targets. It is designed to directly link monitoring of the problem with the actions taken to deal with it. The Kunming-Montreal Global Biodiversity Framework (CBD, 2022a) now extends this, using a theory of change for accelerating action to achieve biodiversity goals for the planet and people (CBD, 2021a); it distinguishes four types of response, i.e., input, process, output and outcome (OECD, 2019; **Table 6.5**). This more detailed and specific identification of the types of responses

Table 6 5 **Four types of societal responses that can be measured and monitored for the purpose of limiting the spread and reducing the impacts of invasive alien species.**

The four types of responses are in the context of a DPSR framework. Adapted from OECD (2019), with the addition of invasive alien species-specific examples.

Response type	Definition	Invasive alien species examples
Input	Measures the material and immaterial pre-conditions and resources – both human and financial – provided for an activity, project, programme, or intervention	• Budget allocated for invasive alien species research, education, monitoring, prevention and control • Number of staff allocated to invasive alien species monitoring, prevention and control
Process	Measures the progress of processes or actions that use inputs and the ways in which programme services and goods are provided	• A national inter-Ministerial Committee for biosecurity established • Targeted education programmes for local communities affected by invasive alien species
Output	Measures the quantity, quality and efficiency of production of goods or services because of an activity, project, programme or intervention	• New legal or policy instruments • Studies such as national invasive alien species assessments completed • The costs of invasive alien species integrated into national accounts
Outcome	Measures the intermediate broader results achieved through the provision of outputs	• Increased eradications of invasive alien species • Reduced ranges of priority invasive alien species • Reduced impacts of invasive alien species

Box 6 3 The Driver-Pressure-State-Response framework for invasive alien species.

This framework **(Figure 6.6)** is intended to guide investment in monitoring and to enable evidence-based causality to be assigned to the relationships among drivers affecting biological invasions (**Chapter 3**, **section 3.5**), invasive alien species and their impacts (**Chapter 4**) and societal responses to dealing with the problem (**Chapter 5**). The indicators listed under each part of the framework below are examples from the application of this framework to the Antarctic (for a global example see McGeoch *et al.,* 2010). For example, trends in invasive alien species eradication at different scales (response) lead to reduced numbers of alien and invasive alien species (pressure) and reduced extinction risk of species threatened by invasive alien species (state). Trends in the number of tourists in the region (driver – note that the term driver in this context differs from its general use in this assessment) provide the information needed to inform policy (response).

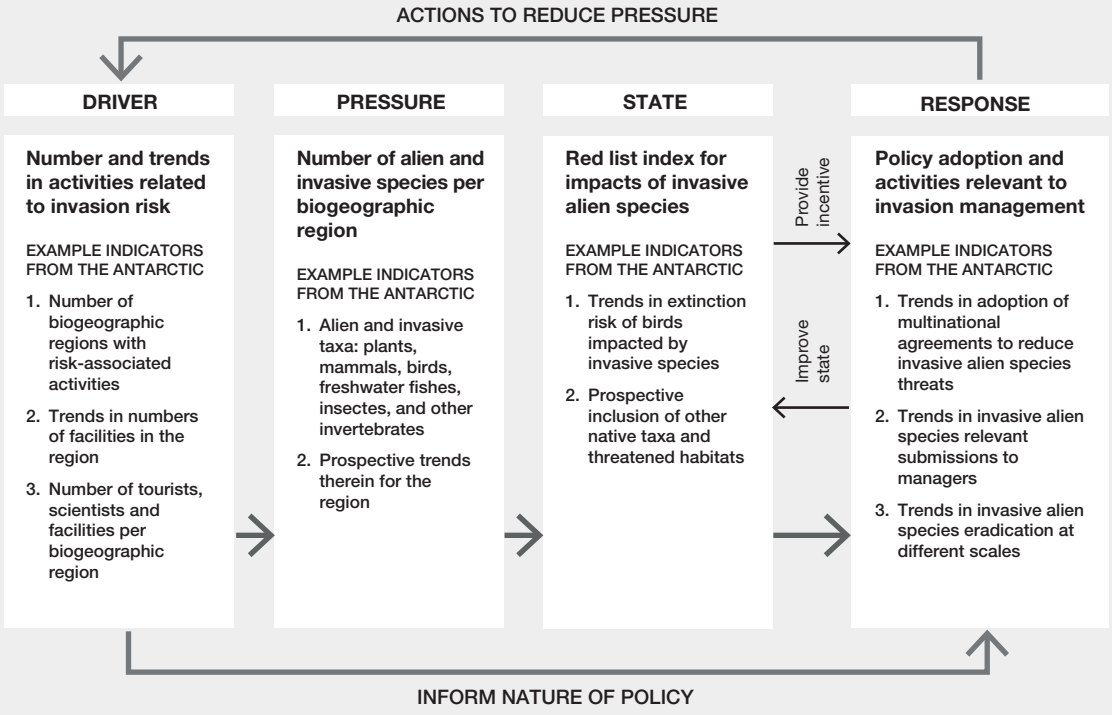

Figure 6 6 Driver-Pressure-State-Response (DPSR) framework for invasive alien species in the Antarctic context.

The DPSR applied to the Antarctic context as an example (non-bold text). Adapted from McGeoch *et al.* (2010, 2015), https://doi.org/10.1111/j.1472-4642.2009.00633.x, https://doi.org/10.1016/j.gloenvcha.2014.12.012, under license CC BY 4.0 and Elsevier license 5406200304811 respectively.

needed to bring about urgent positive change is intended to strengthen the power of monitoring, analysis and reporting (**section 6.6.2**; CBD, 2021b). In other words, if these four responses are effective, they would result in a reduction in invasive alien species pressure and an improvement in the state of socioecological systems negatively impacted by invasive alien species (**section 6.6.2**; Essl *et al.,* 2020).

The DPSR and theory of change frameworks are valuable strategic governance tools for biological invasions because, by design (OECD, 2019), they explicitly connect the causes (drivers) facilitating biological invasions, the size of the problem (pressure), its impact (state) and societal responses to dealing with it (McGeoch *et al.,* 2010; **Box 6.3**), although there are currently gaps in its application and implementation (Vicente *et al.,* 2022). By tracking change in each of these components (for example, using indicators), it becomes possible to design evidence-based, well-motivated and targeted policies for invasive alien species. The framework further makes it clear that the type, size and effectiveness of societal responses will determine the extent to which drivers decline (for example McGeoch *et al.,* 2015; **Box 6.3**). Importantly, the focus of the Kumning-Montreal Global Biodiversity Framework is on the "R, response" in

DPSR, *via* a theory of change, so that the slow progress of implementation can be accelerated.

6.2.2 Identifying the challenges of governing biological invasions

Environmental governance involves increasingly complex and interconnected arrangements, and the governance for biological invasions is no exception (Andonova & Mitchell, 2010; Gilek & Karlsson, 2016). Despite notable successes (**Chapter 5**, **section 5.5**), there are shortcomings in the prevention and control of invasive alien species, leading to a sustained global presence of invasive alien species introductions (**Chapter 2**, **section 2.2**). Understanding the underlying reasons for governance and management failures, across multiple environments, regions and taxonomic groups of invasive alien species helps to design better response options. Ten features emerged from a review of the governance challenges posed by invasive alien species.[4] These challenges are often interdependent (one may drive another for example) and jointly undermine effective prevention and control efforts (Jacobs, 2017; Linke *et al.,* 2016; J. Reed *et al.,* 2016). These key challenges are outlined below as the foundation for the options discussed in **section 6.2.4** and in the rest of this chapter.

(1) Complexity

The governance for biological invasions is considered to be complex because the process of biological invasions is naturally dynamic in space and time (**Chapter 1**, **section 1.4**). It has multiple stages and drivers, involves a large and diverse set of stakeholders, and crosses jurisdictional boundaries (Brenton-Rule *et al.,* 2016; Liu *et al.,* 2018; **Figure 6.7**; **Chapter 1**, **section 1.5.1**). The dynamic and difficult-to-predict behaviour of new technological options (such as the potential use of gene drives; **Chapter 5**, **section 5.4.4.2.j)** adds another level of complexity (Mitchell *et al.,* 2018). Context-specific application of integrated governance for biological invasions (**Glossary**) thus involves multiple trade-offs and the consideration of social, technological and ecological contexts and risks (Lubell *et al.,* 2017) across all levels of governance (Lansink *et al.,* 2018; Riley, 2012; **Figure 6.7**).

(2) Uncertainty

A high degree of uncertainty is associated with the biological invasion process because many species are involved and the likelihood of any species invading is determined by a combination of multiple biological, driver and pathway characteristics (Cooney & Lang, 2007; Udovyk & Gilek, 2013; **Chapter 1**; **Chapter 3**; **Chapter 5**, **section 5.2.2.3**; **Figure 6.7**). Biological invasion processes are non-linear and the uncertainty is "inherent, fundamental and persistent" (D. C. Cook *et al.,* 2010; Cooney & Lang, 2007). The outcomes of this complexity are difficult to predict within specific, narrow contexts, and therefore understanding the likely success of interventions is also difficult (Moon *et al.,* 2017; Smolarz *et al.,* 2016). Time lags (**Glossary**) between different parts of the invasion process, and in policy and management responses to invasive alien species, add to this uncertainty (**Chapter 1**, **section 1.4.4**; **Chapter 2**, **section 2.2**; Jacobs, 2017; J. Reed *et al.,* 2016).

(3) Information availability, flow and access

Information silos across stakeholder groups hinder effective governance (Collins, 2018; Nourani *et al.,* 2018; Peltzer *et al.,* 2019). Effective, sustained communication and collaboration across large, multi-layered networks is however difficult to achieve and has a high transaction cost (Lubell *et al.,* 2017; Nourani *et al.,* 2019). The flow of information relevant to biosecurity within and across countries and trading partners is also limited (D. C. Cook *et al.,* 2010). Actors involved at different scales and levels of governance tend to have access to different types of knowledge (Omondiagbe *et al.,* 2017). This includes the gap between science and practice (Aslan *et al.,* 2009; Esler *et al.,* 2010). There is also an imbalance of information between those who bear the costs of invasive alien species (affected actors; those who tend to have good knowledge of invasive alien species), and the actors responsible for exacerbating biological invasion risk (causal actors; **Glossary**; **section 6.6**; Cook *et al.,* 2010).

(4) Over-reliance on hierarchical governance

The currently dominant, hierarchical forms of governance for biological invasions tend to be centralized, top-down, process-heavy and reactive and, while necessary, are on their own not adequate for preventing and controlling invasive alien species (Cook *et al.,* 2010; Evans *et al.,* 2018; Reed & Curzon, 2015; **Figure 6.7**). Policy models can rely too heavily on rigid, non-adaptive, top-down approaches (Cooney & Lang, 2007). Hierarchical governance can be slow, culturally inappropriate, and not in step with the latest technological developments or scientific understanding (Barnhill-Dilling *et al.,* 2019; Boström *et al.,* 2016; Head & Atchison, 2015; Hughes & Convey, 2014; Trump *et al.,* 2018). Invasive alien species differ in key ways from other drivers of change in nature; for example, a strong precautionary approach (**Glossary**) that is often not enabled by traditional governance approaches is crucial (T. Evans *et al.,* 2018; Smolarz *et al.,* 2016). In addition, the power imbalances that can develop under highly centralized governance can lead to, for example, incoherent policy,

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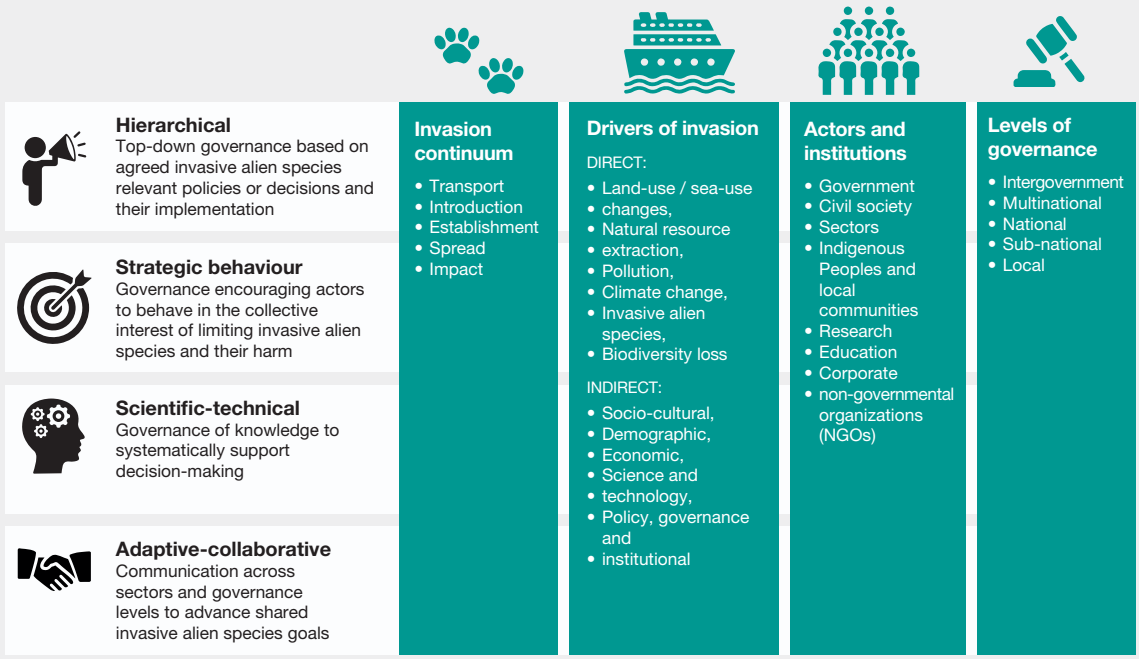


Figure 6 7 **The complex socioecological system characterizing biological invasions.**

The complex socioecological system (vertical boxes) that characterizes biological invasions and their management, and the four, complementary governance models (horizontal boxes) needed to enable successful policy implementation through integration within and across these components of the system (**section 6.2.4**). Data from: IPBES-PEG (2019b).

disengagement, or conflict amongst the broad range of stakeholders affected by invasive alien species (Neale & Macdonald, 2019; A. L. Smith *et al.,* 2013). It is now widely recognized that governments as decision-making authorities are necessary but insufficient for effective invasive alien species prevention and control (Miyanaga & Nakai, 2021; **section 6.2.3.1**).

(5) Fragmentation of policy instruments and their application

Current policy on invasive alien species and its implementation is often fragmented, with multiple, often isolated decision-making centres. As a result current policy is less effective than it could be (Gilna *et al.,* 2014; Nourani *et al.,* 2019; Praseeda Sanu & Newport, 2010; Rudd *et al.,* 2018). At the highest level, as assessed by Outhwaite (2018), there is no "full and coherent applicable body of international law". This fragmentation also includes policy differences between levels of governance and between actors and institutions, e.g., across industry sectors such as agriculture, forestry and the environment **(Figure 6.7)**, between countries and regions, and national and subnational levels of governance (Lubell *et al.,* 2017; P. Martin *et al.,* 2016). Fragmentation can result in, for example, overlapping jurisdictions, incompatible objectives, and unbalanced power relations (Visseren-Hamakers, 2015). Fragmentation of risk communication mechanisms can also undermine prevention and control efforts and public confidence (Jonsson *et al.,* 2016).

(6) Externalities

The negative impacts of invasive alien species often occur outside of the social or economic contexts responsible for their introduction and spread (**section 6.3.1.2**, also called telecoupling). For example, the cost of invasive alien species impacts are not included in the price of traded goods (Stoett, 2010). Invasion risk is sometimes not considered in the development of new agricultural and forestry technologies (Driscoll *et al.,* 2014), when deploying disaster relief aid or when developing international assistance programmes (Murphy & Cheesman, 2006); insect pests can be unintentionally imported with products used to rebuild infrastructure after natural disasters (**Chapter 3**, **section 3.2.2.2**). Negative environmental consequences of invasive alien species are often spatially and temporally diffuse, and this can undermine the legitimacy of environmental concerns (Neale & Macdonald, 2019). Biological invasion as an unintended consequence of trade is an example of a spill-over system, and spill-over effects can tend to be neglected in governance systems (J. Liu, Dou, *et al.,* 2018). The costs, liability and responsibilities for biological invasions need to be balanced between those directly responsible for species introductions and the general public, because health and

biodiversity are a public good (i.e., nature's contributions to people and good quality of life; Outhwaite, 2010). One consequence of treating invasive alien species as an externality (**Glossary**) is that the welfare of the supply-side of trade is considered in isolation (D. C. Cook *et al.,* 2010). The trade-offs that occur as a result of unaccounted-for externalities result in conflicting interests (Hewitt & Campbell, 2007; Marire, 2015; Rouillard *et al.,* 2018; A. L. Smith *et al.,* 2013). Trade-offs also become increasingly political and difficult to resolve as they shift from within particular governance systems or sectors to between and outside of them (Visseren-Hamakers, 2015).

(7) Hurdles to implementation of policy

Although the arguments for invasive alien species policy implementation are empirically well supported, the extent and success of existing policy at international, national and sub-national scales is highly variable (**Figures 6.2**, **6.3**, **6.4** and **6.5**) and considered inadequate (Leadley *et al.,* 2014). Differences exist in the extent to which regulatory measures are implemented across countries (Brenton-Rule *et al.,* 2016) and laws are not always supported by regulation or implementation plans (Riley, 2012). There is no international authority, global coordination, or oversight mechanism for all invasive alien species, and the implementation of biosecurity practices under trade agreements is inconsistent (Stoett, 2010). There are several reasons why both policy and management implementation are challenging, including for example austerity measures and resource shortages (VanNijnatten, 2016), lack of capacity and expertise (Angulo & Gilna, 2008), as well as a number of the other challenges outlined in this section. Often there is a lack of monitoring to gather scientific evidence to support effective implementation, including information to evaluate the success of management approaches, such as knowledge generated from adaptive management (**Glossary**; Reed *et al.,* 2016; Smolarz *et al.,* 2016).

(8) The need for collective action

Effective prevention and control of invasive alien species can be achieved by cooperating and building of trust and social norms across actors, institutions, levels and sectors (**Figures 6.7** and **6.8**; McKiernan, 2018). However, conflicting interests and diverse values and perspectives mean that prevention and control programmes often fail (Graham *et al.,* 2019; Guerrero *et al.,* 2015; Smolarz *et al.,* 2016; **Chapter 1**, **section 1.5.2**; **Chapter 5**, **section 5.6.1.2**). For example, ineffective prevention and control can occur when individual land managers have an incentive to avoid invasive alien species control costs, thereby resulting in risks to others (Graham *et al.,* 2019). Similarly, actors that benefit from activities that increase risk of invasive alien species often have little incentive to acknowledge the risks and impacts of invasive alien species on other actors (Angulo & Gilna,

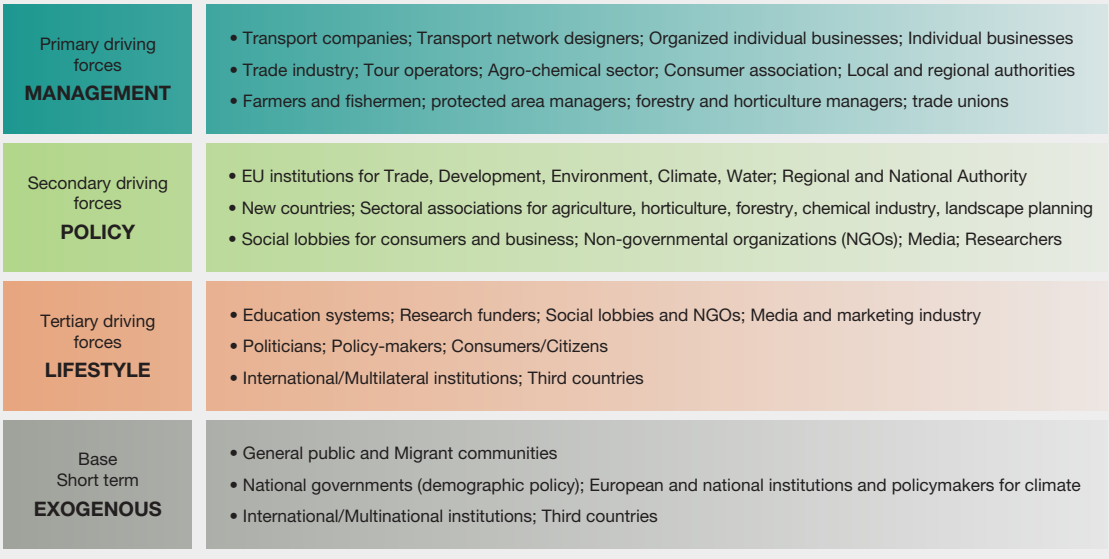


Figure 6 8 **An example of the many relevant stakeholders for managing biological invasions from the Ebro River, Spain.**

There are four categories of stakeholders (on the left) and examples of stakeholders (on the right) involved in decision-making that affects the outcome of biological invasion, based on freshwater invasive alien species in the Ebro River, Spain. Adapted from Rodríguez-Labajos *et al.* (2009), https://doi.org/10.1016/j.ecolecon.2009.08.022, under copyright 2009 Elsevier B.V.

2008; Lubell *et al.,* 2017). Tensions between free trade and the governance of biosecurity risk further undermine the collective action (**Glossary**) that is needed on invasive alien species (Lansink *et al.,* 2018). The context-dependence of social settings and, therefore, of appropriate design of collaborative solutions, exacerbates this challenge (Lubeck *et al.,* 2019; P. Martin *et al.,* 2016). The transaction costs of administration, supervision and capacity development for implementing management of biological invasions can also undermine collective action (P. Martin *et al.,* 2016).

(9) Awareness, perception and values

There is often a lack of awareness and understanding, or neglect, of invasive alien species and their negative environmental, social and economic impacts. This is the case amongst a number of sectors, actors and stakeholders including amongst policymakers (**Chapter 1**, **section 1.5.2**; Moon *et al.,* 2015; Stoett, 2007). Perceptions of invasive alien species can also vary widely for several reasons (Shackleton, Richardson, *et al.,* 2019; Zengeya & Wilson, 2020), such as a focus on economic (instrumental) *versus* intrinsic and cultural (relational) values (**Chapter 1**, **section 1.5.2**; Leventon *et al.,* 2021). Understanding and the concept of biological invasion risk differs across and within groups and communities (Maclean *et al.,* 2022). Local communities, for example, may be very familiar with individual invasive alien species and their negative impacts on good quality of life, but remain unaware of the concept of biological invasions and the context of management and policy (Shrestha *et al.,* 2019; **section 1.6.7.1 (ii)**). Lack of awareness and different values can result in a lack of public support (Vane & Runhaar, 2016), exacerbate differing perceptions, and ultimately undermine collective efforts to manage biological invasions (Kohl *et al.,* 2019; **Chapter 3**, **section 3.2.1**). Public and private sector consultation and engagement can successfully underpin invasive alien species prevention and control efforts when they include effective risk communication and rely on the contributions of stakeholders and Indigenous Peoples and local communities (Ekanayake *et al.,* 2020; Falkenmark, 2007; Jonsson *et al.,* 2016).

(10) Conflicting interests and trade-offs

Conflicting interests and trade-offs happen when externalities are not considered and when a priori risk assessment is not done (e.g., Driscoll *et al.,* 2014), or is not inclusive of sectors and stakeholders (Woodford *et al.,* 2016; Zengeya *et al.,* 2017). Since some invasive alien species can have both positive and negative impacts, control and eradication programmes can spark conflict (**Chapter 1**, **Figure 1.1**, **section 1.5.2**; **Chapter 4**, **section 4.1.2**). There is also the often challenging need to strike a balance between short term needs and the long-term maintenance of good quality of life, alongside the uncertainty and challenges in making predictions outlined above.

6.2.3 Options for strengthening the governance for biological invasions

"Current environmental challenges call for new interdisciplinary approaches at the interface of natural and social sciences, framed in a context of governance and decision-making by actors from the state, market and civil society" (Padt *et al.,* 2014).

The challenges outlined in the previous section provide a platform for identifying a range of options for strengthening the governance for biological invasions. Governance-related options that emerged from the literature review[5] are summarized in **Table 6.6** under six general topics: strategy; multilevel and multisector governance; coordination and cooperation; policy environments that are enabling; research and information and their communication; and governance capability, capacity and resourcing. Governance provides an overarching instrument for dealing with complex systems and is considered one of the most important factors to achieve desired environmental outcomes (Bennett & Satterfield, 2018). The many considerations and elements of

5. Data management report available at: https://zenodo.org/doi/10.5281/zenodo.5762739

Box 6 4 Restoring the Kafue flats: a case study of integrated management and effective governance of the invasive shrub, *Mimosa pigra* in Zambia.

Impact on good quality of life and protected areas: In the early 1980s, *Mimosa pigra* (giant sensitive plant) invaded the Kafue Flats – a 6,500 km^2 floodplain located in the southern region of Zambia and a designated Wetland of International Importance under the Ramsar Convention. The flood plain is world-renowned for its abundant floodplain wildlife, including the endemic antelope, *Kobus leche kafuensis* (Kafue Lechwe), and rich diversity of birdlife including the *Bugeranus carunculatus* (wattled crane) and *Balearica regulorum* (gray crowned-crane). The flood plain hosts two national parks, surrounded by buffer zones inhabited by smallholder farmers and fishers, whose livelihoods depend on the land and water resources of the floodplain. It has been suggested that the *Mimosa pigra* invasion was triggered by hydrological alterations resulting from hydropower dams (Blaser, 2013; Mumba & Thompson, 2005). What started as a small infestation of about

Box 6 4

2 ha spread rapidly and covered over 3000 ha of the floodplain (Blaser, 2013; Shanungu, 2009; Solomon Genet, 2007; Thomas, 2007). Consequently, the native floodplain vegetation was replaced by *Mimosa pigra*, and many wildlife species of conservation concern including the *Kobus leche kafuensis* and *Bugeranus carunculatus* were displaced as their habitat shrank (**Glossary**; Blaser, 2013).

Multiparty governance: In 2017, The International Crane Foundation/Endangered Wildlife Trust Partnership (ICF/EWT Partnership), World Wide Fund for Nature (WWF) – Zambia, and Zambian Department of National Parks and Wildlife (DNPW) embarked on a three-year cooperative project to address the continued spread of *Mimosa pigra*, restore the floodplain grasslands and enhance their ability to support important biodiversity of the flats, and control up to 95 per cent of the baseline cover of *Mimosa pigra* in an effort with substantial community involvement.

Stakeholder and Indigenous Peoples and local communities involvement and benefits: The project also focused on developing the Zambian Department of National Parks and Wildlife local staff capacity in invasive plant management and habitat restoration. This included ecological research to enhance global understanding of large-scale *Mimosa pigra* control methods and their measurable impact on biodiversity, livelihoods options, and the broader economy through agriculture, fisheries and tourism **(Figure 6.9)**. The project took an ecosystem approach with a focus on the wider Kafue Flats ecosystem – including the two National Parks and the buffer zones – with a strong emphasis on a multi-sector approach in the management of the invasive alien species.

The project intended to engage non-traditional stakeholders including the private sector. The integrated management approach adopted combined physical, chemical and biological control options (**Glossary**).

Sustainable successes: By 2020, all management options described above had been implemented. About 450 workers from local communities were employed to undertake community-based restoration work through large-scale physical removal and chemical spraying of *Mimosa pigra*. Biological control trials through the importation and direct release of the control agent *Carmenta mimosa* commenced in May 2019. Six months after direct release, a monitoring exercise was undertaken to determine if there were signs of the control agent's survival. The presence of adults and actively feeding larvae six months after the introduction indicated that the biocontrol agent survived successfully and was reproducing. By June 2020, the area invaded by *Mimosa pigra* had been reduced by approximately 68.8 per cent of the total invaded area at baseline. Ecological surveys indicate that there is regeneration of native vegetation in areas previously covered by *Mimosa pigra* and use of the restored sites by herbivores including the *Kobus leche kafuensis*, as well as various species of resident and migratory waterbirds including breeding pairs of *Bugeranus carunculatus* and *Balearica regulorum*. Some members of the community employed by the project had been able to use their income to invest in livestock and improved housing while others had used it to educate their children.

Long-term efforts were undertaken to restore water conditions through environmental flow releases from the dam upstream that might limit future *Mimosa pigra* establishment.

Figure 6 9 ***Mimosa pigra* (giant sensitive plant) in Zambia.**

Left: Clearing of *Mimosa pigra* from the Kafue flats floodplain. Right: control of *Mimosa pigra* maintains habitat for the endemic *Kobus leche kafuensis* (Kafue Lechwe) and other biodiversity in this wetland of international importance. Photo credits: Gareth Bentley (WWF Zambia) – Copyright (left) / Patrick Bentley (WWF Zambia) – Copyright (right).

successful governance for biological invasions are well illustrated by the case of the invasive alien shrub, *Mimosa pigra* (giant sensitive plant), in Zambia **(Box 6.4)**.

As context for the sections to follow, three key points can be made about the literature and evidence in support of governance approaches for biological invasions:

- While there is literature on the topic of biological invasions governance (assessed and drawn upon in the formulation in this section), only a small proportion of this literature critically evaluates, with empirical data in an invasive alien species context, the strengths and weaknesses of particular or alternative governance models and overarching governance systems.
- The most useful and evidence-based literature comes from comparatively extensive and relevant work on environmental governance more broadly.
- As a result, many of the options, tools and approaches are not particular to biological invasions and evidence for them is steeped in different domains and areas of expertise (Weitz *et al.,* 2017). Since an assessment of environmental governance is beyond the scope of this assessment – the field is interdisciplinary and itself developing rapidly – this section draws on some of the general frameworks and thinking on environmental governance that align with insights from biological invasion-specific literature, and refers to key findings in depth only where there is evidence specific to biological invasions.

Table 6 6 **Overview of governance response considerations.**

This table presents six types of response options (left column), and examples of relevant support tools, methods and frameworks (middle column) alongside examples of publications (right column).

Response option	Examples of relevant support tools, methods and frameworks	Example publications
Strategy, including approaches to deal with inherent complexity **(sections 6.2 to 6.7)**	• Empirical analysis of invasive alien species policy and governance • Objective review and evaluation • National invasive alien species Strategy and Action Plans • Sustainability: Environmental – social – economic • Pressure-State-Response type models • Ecosystem-based approach to management (EBM) • Adaptive governance (**Glossary**) model	Barnhill-Dilling *et al.,* 2019; Boström *et al.,* 2016; Chaffin *et al.,* 2016; Cooney & Lang, 2007; P. Martin *et al.,* 2016; McGeoch, Shaw, *et al.,* 2015; Rudd *et al.,* 2018; Smolarz *et al.,* 2016; Termeer *et al.,* 2010
Multi-level and sectoral integration **(sections 6.3, 6.7)**	• Integrated governance for biological invasions • Transnational environmental alliances • Conflict resolution • Negotiation of values • Inter-agency coordination to co-ordinate across policies and agencies and to monitor (stakeholder and Indigenous Peoples and local communities-wide or) government-wide activity. • Multidisciplinary, comparative research on invasive alien species policy regimes (**Glossary**)	Bennett & Satterfield, 2018; Daviter, 2017; Herrick, 2019; Justo-Hanani & Dayan, 2020; Visseren-Hamakers, 2015; Weitz *et al.,* 2017
Coordination and collaboration across international and regional mechanisms **(section 6.2.3.4)**	• Stakeholder and Indigenous Peoples and local communities mapping • Actor network analysis • Measures to build public support • Bridging organizations (**Glossary**) • Extension personnel • Institutions that build cooperation amongst relevant actors • International cooperation on information sharing, monitoring, implementation and best practice	Angulo & Gilna, 2008; D. C. Cook *et al.,* 2010; Gilna *et al.,* 2014; Lubell *et al.,* 2017a; Nourani *et al.,* 2019; Stoett, 2010
Policy that is enabling, including the consideration of inclusion, the distribution of power and adaptation **(sections 6.4, 6.5)**	• Policy risk analysis • Assess the distribution of costs and benefits of governance actions • Stakeholder and Indigenous Peoples and local communities mapping • Ecosystem Based approach to Management (EBM) • Mechanisms to identify the need for and enable the establishment of temporary task forces • Networked, polycentric governance (**Glossary**) • Legitimize decision-making at local scales • "Landcare" model	Catacutan *et al.,* 2009; Chaffin *et al.,* 2016; Linke *et al.,* 2016; Marshall *et al.,* 2016; P. Martin *et al.,* 2016; P. Martin & Taylor, 2018; McKiernan, 2018; Moon *et al.,* 2015; Peltzer *et al.,* 2019; Smolarz *et al.,* 2016

Table 6 6

Response option	Examples of relevant support tools, methods and frameworks	Example publications
Effective communication of research, information and learning **(section 6.6)**	• Biosecurity collectives for information sharing • Structured process by which knowledge can influence relevant actors • Knowledge sharing platforms and infrastructures at multiple scales • Clear assignment of responsibilities for risk communication • Public information campaigns • Context-specific messaging to encourage strategic behaviour • Information brokers	D. C. Cook *et al.,* 2014; Cooney & Lang, 2007; Jonsson *et al.,* 2016; Lubeck *et al.,* 2019, 2019; Moon *et al.,* 2015; Nourani *et al.,* 2019
Governance capability, resourcing and capacity **(sections 6.2 to 6.6)**	• Build capacity in key governance capabilities • Campaigns to make necessary technical concepts part of the public agenda • Consider gains and losses from activities (e.g., trade) in negotiations • Cost sharing arrangements • Assess potential inequity and incapacity	D. C. Cook *et al.,* 2014; Ford-Thompson *et al.,* 2012; Jonsson *et al.,* 2016; P. Martin *et al.,* 2016; P. Martin & Taylor, 2018; Outhwaite, 2017; Termeer *et al.,* 2016; Termeer & Dewulf, 2014

6.2.3.1 Employing multiple models of governance

Together, four complementary models of governance (1-4 below) provide a high-level framing for comprehensive governance and for guiding the development of national invasive alien species strategies (**Figure 6.6**; IPBES, 2019b). These models provide alternative but, importantly, not mutually exclusive mechanisms for bringing about policy implementation, and together they encompass a focus on all relevant actors (Primmer *et al.,* 2015; **Figure 6.7**). Each of these models thus plays a role in the comprehensive and strategic governance for biological invasions; each encompasses options for strengthening governance that are outlined in further detail in **sections 6.3** to **6.6**.

(1) Hierarchical governance: Top-down governance based on agreed invasive alien species -relevant policies or decisions and their implementation

Governments enact legislation, develop aligned regulatory policy, and provide the funding needed to implement risk assessment and surveillance (**Glossary**; Lodge *et al.,* 2006), i.e., provide a comprehensive, centralized and science-based control regime, administered through one or more national agencies (Herrick, 2019). Hierarchical governance provides an existing and necessary backbone as well as, *via* legislation and regulation, the strongest category of instruments for invasive alien species implementation and control. While shortcomings in the hierarchical governance for biological invasions are identified and discussed above and in multiple sections of this assessment (**section 6.2.2.(4)**), hierarchical multilateral and national policy and legislative instruments will remain central to governance for biological invasions (**section 6.3**).

(2) Strategic-behavioural governance: Governance encouraging actors to behave in the collective interest of limiting invasive alien species and their harm

Beyond legislated policy, broad stakeholder and Indigenous Peoples and local communities support is essential to the effectiveness of invasive alien species prevention and control, including the full breadth of relevant actors (**Figures 6.7** and **6.8**; Vane & Runhaar, 2016). Strategic institutional arrangements can create enabling environments for collaboration, achieving agreement, and enhancing effective action. Perceived costs and risks of invasive alien species as well as opposition based on moral or ethical considerations can undermine management outcomes, whereas community groups, lobbies and public support can be particularly powerful in altering actions that affect invasive alien species outcomes (Crowley *et al.,* 2019; P. Martin *et al.,* 2016). Public support and voluntary, collective action are needed, for example, to manage weeds that cross boundaries. The willingness of land owners to participate in interventions is determined by many individual, collective and context-specific factors (Finkel & Muller, 1998; Lubeck *et al.,* 2019; Vane & Runhaar, 2016). The research and design of tailored behaviour-change strategies, effective communication and outreach and the analysis of policy risk to anticipate undesirable outcomes are all key components of successful strategic-behavioural governance (Lubeck *et al.,* 2019). The net balance of incentives and disincentives determines the likelihood of participation in invasive alien species prevention and control efforts. The focus of strategic-behavioural governance is therefore on social and

economic mechanisms for bringing about public support and behavioural change (Martin *et al.,* 2016; **sections 6.4** and **6.5**).

(3) Scientific-technical governance: Governance of knowledge to systematically support decision-making

Effective governance for the prevention and control of invasive alien species demands a wealth of information, efficient delivery of this information, and context-appropriate means by which to communicate it. Scientific-technical governance deals with the governance of knowledge within and across the components of the socioecological system that characterizes biological invasion (**Figure 6.7**; McGeoch & Jetz, 2019). This includes the role of international collaboration in delivering and sharing knowledge (Latombe *et al.,* 2017) and regional early warning and information systems for invasive alien species. Scientific-technical governance includes the structure of information systems and platforms, assignment of responsibilities for data and information generation, sharing and communication (including risk communication; **Chapter 5**, **section 5.2.2.1.h**). It also includes strategies for delivering and communicating different types of information to different stakeholders. For example, the European Commission has developed an invasive alien species information system (European Alien Species Information Network, EASIN) that ensures transparent and authoritative data on invasive alien species (European Environment Agency, 2010a). Scientific-technical governance could also involve introducing, or strengthening existing, mechanisms that support a more ecosystem-based approach to governance, i.e., that includes systematic collection of essential data, use of best available evidence, and impact assessments as a pre-condition for new activities, policy change and involvement of stakeholders (Smolarz *et al.,* 2016).

(4) Adaptive-collaborative governance: Communication across sectors and governance levels to enhance shared invasive alien species goals

This model of governance involves a systematic approach to improve the planning and management of invasive alien species by "learning from doing". It involves joint formulation of management objectives, specification of multiple management options, forecasting and estimating uncertainty, implementing management options, monitoring (social learning) to improve forecasting and reduce uncertainty, and changing management responses throughout a policy cycle (**Glossary**; Niemiec *et al.,* 2019; Richardson *et al.,* 2020). To date, many approaches to governance for biological invasions that refer to adaptive management have included only scientists, other experts or formal invasive alien species managers, and top-down modes of governance. In contrast, the concept and practice of adaptive collaborative governance and management are based on the involvement of stakeholders in decision-making at all levels, and on the establishment of vertical and horizontal institutional linkages spanning governance scales. These linkages support integrating and sharing knowledge. Adaptive-collaborative governance and management is ultimately "concerned with enhancing and including the capacity of all actors with a stake for sustainably managing the resource at hand" (Plummer *et al.,* 2012). Options involving this model of governance are covered in further detail in **section 6.4**.

6.2.3.2 Developing effective strategy for biological invasions

Recognizing the significance of strategic planning for invasive alien species, one indicator under the SDGs (Indicator 15.8.1) aims to track the percentage of countries with national strategies for preventing and controlling invasive alien species (UN, 2021). The need for strategy to deal with biological invasions is driven by:

1. The sheer size of the problem and the need to prioritize resources and actions;

2. The multidimensional and interconnected nature of the problem across invasion stages (**Glossary**), sectors and actors; and

3. The interdependence between invasion and other forms of environmental change.

Strategic planning

The way strategies are designed, their content and the incorporation of good and environmental governance principles are key to guarantee their effectiveness (**Chapter 5**, **section 5.2** for more information on evidence-based decisions). In complex contexts, such as those faced by countries dealing with invasive alien species and their impacts, strategic planning can be improved by clear and cyclical assessment, option formulation, action, and re-assessment to achieve the goals of prevention, control and minimization of negative impacts (Andonova & Mitchell, 2010), including regular, objective review and evaluation (Martin *et al.,* 2016; **Table 6.6**). Given limited resources, strategic planning can drive prioritization, including determining which species need prevention, control, or adaptation responses (McGeoch *et al.,* 2016). The strategic planning phase would consider all four governance models discussed above as part of a comprehensive strategy. Widely accepted steps in the development of strategy include: (1) evidence-based situation analysis; (2) development of a strategy and action plan; (3) identification and prioritization of tools and methods to enable strategic action, including legislation, financing,

institutional arrangements, stakeholder and Indigenous Peoples and local communities participation; and (4) mechanisms to ensure implementation (Falkenmark, 2007).

National strategies

National strategies are critical for achieving invasive alien species goals and targets, as this is the level at which legislative and resourcing commitment by countries is strongest (CBD, 2020c). National strategies for invasive alien species have been called for, *inter alia*, to design implementation regimes, for example in the form of national invasive alien species strategy and action plans or national-level biosecurity strategies (Sustainable Development Solution Network, 2021). Such strategy could aim to include or address:

- The means to achieve coherent legislative frameworks;
- Coordination mechanisms to manage and communicate with the range of government and non-government sectors and actors involved;
- A coordinating body able to harmonize law such that no conflicts exist between sectors (Riley, 2012; Shine *et al.,* 2005);
- Collaborative and inclusive definition of goals and objectives for invasive alien species across sectors and levels that can be integrated into national strategies (Barnhill-Dilling *et al.,* 2019; Praseeda Sanu & Newport, 2010; Smolarz *et al.,* 2016);
- The identification, prioritization and management of pathways and drivers;
- Prioritizing established and future invasive alien species threats and committing related resources accordingly;
- Optimizing surveillance, early detection and rapid response, eradication, containment and control programmes at local and sub-national scales;
- The prioritization of national strategies to improve the efficiency of deployment of limited resources for invasive alien species prevention and control;
- National strategies can also define instruments and processes to encourage shared efforts and commitments, and understanding of the specific roles of all sectors and actors (Indigenous Peoples, community and industries) and multi-scale coordination of response programmes (e.g., Maclean *et al.,* 2021);
- Mechanisms for specifying the distribution of responsibility (financial, planning, infrastructure, etc.) amongst stakeholders (Smolarz *et al.,* 2016);
- Coordination and justification for efficient and effective investment (whether national and sub-national) and appropriate support and reporting on invasive alien species guiding principles **(Table 6.3)**, guidelines, goals and targets under multilateral agreements, in the context of societal and economic goals of sustainable development and international trade;
- Mechanisms to drive institutional and organizational structures that allow for flexible strategic thinking and reflection (Boström *et al.,* 2016) and adaptive cooperation between stakeholders (Smolarz *et al.,* 2016);
- National strategies that address the need for and design of, local and subnational strategies for the eradication of priority species.

6.2.3.3 Including actors across scales, levels and sectors

There is increasing evidence and a growing realization that the involvement of multiple sectors, stakeholders and Indigenous Peoples and local communities, together with the consideration of diverse perspectives and interests, can achieve effective governance and management of biological invasions (Guerrero *et al.,* 2015); thus, a sustainability framework for an invasive alien species strategy could be appropriate (e.g., Barnhill-Dilling *et al.,* 2019; Vaas *et al.,* 2017). Governing invasive alien species within a sustainability framework provides a widely-accepted departure point for national environmental strategies (Nourani *et al.,* 2018), including strategies for invasive alien species. Including stakeholders and Indigenous Peoples and local communities with different knowledge, perceptions and socio-cultural contexts can help achieve shared efforts and commitments, the understanding of the specific roles of all actors, improve the efficiency of proposed mechanisms and build trust (Maclean *et al.,* 2022; Shackleton, Richardson, *et al.,* 2019). In other words, everyone has a role to play in the governance for biological invasions.

Such joint or integrated approaches (**section 6.2.4**) across the components and processes that characterize the socioecological system relevant to biological invasion (i.e., multilevel and multisector governance) can improve the effectiveness and efficiency with which the complexity of the invasive alien species problem can be managed (Lubeck *et al.,* 2019; Stoett, 2007; **Figure 6.7**). While the terms “level” and “scale” are often used interchangeably, they have distinct, complementary meanings in governance for biological invasions. Because of their importance to the design of effective governance systems, these dimensions and the roles that they play are outlined below and discussed in terms of their importance for sectors and networks.

Scales and governance – spatially and temporally continuous structures and processes

One way of viewing governance is through a scaling lens (Padt & Arts, 2014). While the impacts of invasive alien species occur locally, the drivers that facilitate biological invasions operate across scales from global to local, and the impacts also accumulate upwards to affect national and global economies and ecosystem processes (Andonova & Mitchell, 2010; Boström *et al.,* 2016; Termeer & Dewulf, 2014). As a global change phenomenon, biological invasion is both complex and dynamic because it involves interacting social, biological and abiotic environmental dimensions, often with context-specific outcomes (**Chapter 1**, **section 1.5**). Biological invasions are also transboundary in nature. This is a consequence of the fact that species movements are not naturally constrained by geopolitical boundaries: borders can be fluid for stakeholders and Indigenous Peoples and local communities and trade and human movement across natural and geopolitical borders are the primary drivers promoting biological invasion (S. Muller *et al.,* 2009). As a result, solutions for managing biological invasions demand strategy, communication, cooperation, data and information that are similarly geopolitically unbounded **(Figure 6.7)**. Agencies responsible for management are often local and the transfer of knowledge and management technology to this level is crucial (**section 6.6**). Biological invasions and management events at one place or time, and the reporting of such events, have a fundamental bearing on relevant response options at scales beyond which they occur. The process of biological invasion operates continuously across spatial scales from local – sites at which populations of invasive alien species establish or have impact – to the large regions over which invasive alien species are transported, cross borders and spread. Similarly, invasive alien species management spans short-term actions – such as rapid responses to eradicate newly established invasive alien species – to long-term efforts to contain or control well-established invasive alien species in order to mitigate their impacts. Investing in invasive alien species management systems is a long-term endeavour to protect and maintain good quality of life and nature's contributions to people. Therefore, it is appropriate, for example, that invasive alien species information systems, management of invasive alien species, and governance for biological invasions structures account for such scales. All of these information, structures and processes are planned and implemented across multiple spatial and temporal scales of biological organization (i.e., considering genetic diversity and adaptation, species population dynamics, community processes and ecosystem function; Padt & Arts, 2014).

Levels of governance – vertical interactions

Invasive alien species are governed and managed at multiple levels of societal organization, from regional to national and sub-national (**Chapter 1**, **Figure 1.9**). Levels of governance encompass civil society groups, for example, that contribute to weed clearing in local neighbourhoods, to sectoral land-management at a sub-national scale (such as protected and production areas), to states and provinces, countries, regions and broader intergovernmental arrangements (**Figures 6.7** and **6.8**). When a mismatch exists between the level of governance and the scales at which biological invasion occurs, policy and resulting interventions are less likely to succeed (Primmer *et al.,* 2015). Biological invasions policy is relevant and necessary at all levels of governance, and specification of those levels is useful, if not essential, in strategic planning and decision-making (Lescrauwaet *et al.,* 2015). Stakeholders and institutions affected by and responsible for governance for biological invasions operate across either more or less hierarchical or inclusive levels of responsibility and cooperation. At a sub-national level, there are several possible invasive alien species management institutions, such as state/province-wide management programmes (bounded by sub-national government borders), cooperative management areas (delineated by land use or ownership) and volunteer groups (**Figures 6.7** and **6.8**). For example, the Landcare movement across multiple IPBES regions provides a tested option for government-supported, community-led information sharing and action, including partnerships among business, researchers, natural resource management agencies, governments, stakeholders and Indigenous Peoples and local communities, resulting in several successful cases of local implementation (Catacutan *et al.,* 2009; McKiernan, 2018).

Sector governance – horizontal interactions

Invasive alien species prevention and control activities, including legal and regulatory instruments for biological invasions, involve multiple institutions with global (CBD, WTO, IMO) or regional (Council of Europe) mandates and tend to be developed for and organized within key industry sectors (Hulme, 2020). As discussed further in **section 6.3.1**, these sectors include environment and biodiversity, transport, trade, production systems, extraction systems and public health. One main limitation of the current policy regime for managing biological invasions is the narrow sectorial focus, where legal and regulatory instruments focus only on addressing either biosafety or biodiversity issues. The need for information flows and communication across governance systems from different sectors has been identified as a major challenge that undermines the effectiveness of invasive alien species management (Roura-Pascual *et al.,* 2021; **Chapter 5**, **section 5.6.2.2**) and a limitation for effective horizontal integration of invasive alien species management approaches. Moreover, many of these sectors influence public policy and resources (notably production, extraction, development aid and health sectors), so the explicit consideration and inclusion of all sectors is critical for effective governance for biological invasions.

Network governance – horizontal and vertical interactions

From an analytical perspective, and with the purpose of better understanding the roles and interactions among actors, scales, levels and sectors **(Figure 6.7)**, governance systems can be considered as networks (Lubell *et al.,* 2017; Provan & Kenis, 2008; **Chapter 5**, **section 5.6.3.1**). Networks are a useful way to jointly consider the scales, levels and sectors outlined above. For example, the multiple relationship links between stakeholders needed to manage aquatic invasions in rivers in **Figure 6.8** can be viewed and as a network to better understand the strengths, weaknesses and gaps in governance for biological invasions in this freshwater context. A network approach is useful for understanding the roles and contributions of stakeholders and institutions for cooperation and for strengthening the effectiveness of working relationships (Moon *et al.,* 2015; VanNijnatten, 2016). A network view of governance for biological invasions encompasses the concept of polycentric governance (one with multiple centres of power in decision-making) that has been identified as a successful and complementary model for inclusive governance for biological invasions (Marshall *et al.,* 2016; Vaas *et al.,* 2017). Some of the advantages of polycentric governance include better information generation and flow within and across actors (nodes) in the network compared to monocentric governance, as well as short social and physical distances between interacting nodes (Cook *et al.,* 2010, 2014; Vaas *et al.,* 2017; **section 6.4.4**).

6.2.3.4 Coordination and cooperation to support the governance for biological invasions

Regardless of the view taken (scaled, multilevel or multisector, networked, or integrated), governance for biological invasions is achieved through cooperation, coordination and effective communication (Jacobs, 2017; Lubell *et al.,* 2017; McKiernan, 2018; Vaas *et al.,* 2017). Options for enabling integrated governance for biological invasions thus include identifying and supporting stakeholders who are able to play a bridging role across otherwise disconnected nodes of the network, the establishment of formal coordination bodies, and the use of extension personnel (Ekanayake *et al.,* 2020; Nourani *et al.,* 2019; Vaas *et al.,* 2017; **sections 6.2.4** and **6.4**). International networks and partnerships play a decisive role in sharing information, capacity-building, promoting collaboration, and sharing novel tools and techniques to manage biological invasions (**Chapter 5**, **section 5.6.3.1**). For example, sharing of knowledge between native and invaded ranges (**Glossary**) helps to predict entry and establishment risks and the potential impacts of alien species (Nourani *et al.,* 2018). International collaboration is critical in managing biological invasions since the alien species are mobile and do not respect political or legal boundaries (Graham *et al.,* 2019).

Governance for biological invasions is therefore in part a collective action problem that provides collaborative solutions (Hershdorfer *et al.,* 2007; Epanchin-Niell *et al.,* 2010; McLeod & Saunders, 2011; Bagavathiannan *et al.,* 2019) including, for example, public-private partnerships (Mato-Amboage *et al.,* 2019). As outlined earlier, the mobility of invasive alien species means that preventing spread and managing established populations can be achieved through cooperation and coordination across property and jurisdictional boundaries (Graham, 2014; Yung *et al.,* 2015; Howard *et al.,* 2018; **section 6.4**). Achieving such cooperation is challenging because diverse actors have different perceptions and values (**Chapter 1**, **section 1.5.2** and varying levels of interest, skills, resources, capacity, and time to commit to invasive alien species prevention and control (Donaldson & Mudd, 2010; Graham, 2013; Ma *et al.,* 2018; Kropf *et al.,* 2020). Successful collective action would include developing stakeholder and Indigenous Peoples and local communities networks, and building the trust to forge a common understanding of the problem, agree on a common goal, identify measures of success, and encourage participation in individual and group activities (Stallman & James, 2015; Niemiec *et al.,* 2016; Graham & Rogers, 2017; T. M. Howard *et al.,* 2018; Bagavathiannan *et al.,* 2019). Micro-interventions implemented during community engagement activities can increase participation and change social perceptions, such as facilitating increased communication amongst community members, setting collective goals, achieving public commitment, and enhanced visibility of contributions (Niemiec *et al.,* 2019). There are many examples of how local communities have successfully mobilized to collectively manage invasive alien species (**section 6.4.3**).

6.2.3.5 Considering human adaptation to invasive alien species in governance systems

Adaptation to invasive alien species is emerging as a critical consideration for policy and management. Two concepts of adaptation are relevant: the first is “planned” adaptation, derived from a concept used by the Intergovernmental Panel on Climate Change (IPCC), which is “the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state” (IPCC, 2007); the second is “autochthonous” adaptation, defined as “deliberate adaptation actions undertaken by individuals or small social groups that are specific to and occur within a local system, where human populations are ultimately affected” (P. L. Howard, 2019). This type of adaptation has four characteristics: (1) it is deliberate; (2) it refers to individuals and small groups of individuals; (3) it is specific to the locality – specific environmental, social and cultural conditions that prevail in specific places where people live and act and (4) it occurs within a local system, which is affected by multi-scalar drivers and feedbacks, thus

it is affected by many external influences, including planned adaptation (P. L. Howard & Pecl, 2019).

When human adaptation becomes a response

Adaptation is relevant in cases where invasive alien species are established and, for environmental, management, or socio-economic reasons, there may currently be no other option (Kleinschroth *et al.,* 2021). It is also relevant when invasive species impact human well-being and people attempt to manage them or adapt to their impacts (König *et al.,* 2020). Adaptation may be the only option in cases where, due to the type of invasive and invasion scale, resources are unavailable to effectively mitigate or control invasive alien species, such as in forests, rangelands, savannahs, and large water bodies, including oceans (Godfree *et al.,* 2017). It may also be necessary in cases where there are currently no known effective control methods, or effective methods cannot currently be deployed due to non-target effects or strong political, ethical, or social objections to available controls methods. For example, recreational fishing lobbies can stand in the way of formulating invasive alien species regulations (Zengeya *et al.,* 2017; **Box 6.16**). Adaptation may be the only option when invasive alien species generate substantial social, economic or ecological benefit and have been incorporated into socioecological systems to such a degree that control or eradication would generate serious negative socioecological impacts (Bhattacharyya & Larson, 2014; P. L. Howard, 2019; Roder, 2001). When invasive alien species have negative impacts on good quality of life (**Chapter 4**, **section 4.5**), people attempt to change these impacts and, if possible, turn harm to benefit. A review of 70 case studies on adaptation to invasive alien species across the globe found that this is done in many ways – such as managing invasive alien species, using invasive alien species, changing their cropping and livelihood systems to accommodate harmful changes, or using the resources that invasive alien species can in some cases provide (P. L. Howard, 2019). When the impacts are too severe, people may be forced to abandon their homelands altogether or to migrate to find resources such as forage grass in new regions (**Chapter 4**, **sections 4.5.1** and **4.6.3.2**). Adapting to invasive species, then, often means mobilizing and reorganizing relationships and assets within communities, which has knock-on effects not only for individual members but as well for entire communities and socioecological systems (P. L. Howard, 2019).

Governance implications of human adaptation to invasive alien species

The practical and policy implications of such local-level adaptation to invasive alien species are significant. No matter how wide the reach of planned interventions, such adaptation may still be necessary. Governments often have limited resources and rely on local actors and their cooperation to implement invasive management actions (P. L. Howard & Pecl, 2019; Pecl *et al.,* 2019). Adaptations to invasive alien species occur in different spheres of individual, household, or collective activity related to production systems and the enactment of daily life (P. L. Howard, 2019). Local-scale adaptation is an important means to mitigate the impacts of invasive alien species, restore socioecological resilience (**Glossary**) and, where necessary and possible, transform socioecological systems to more desirable and sustainable states. In cases where adaptation includes use of the invasive alien species as a resource, a balance needs to be achieved between local benefits arising from such use and the potential of such use exacerbating negative outcomes from further invasive alien species spread (P. L. Howard & Pecl, 2019).

Understanding and considering human adaptation to invasive alien species can lead to the formulation of policies and practices (related to sectors such as land management and pesticide use) that seek to influence local adaptation in ways that increase adaptive capacity, resilience and sustainability. It is therefore an important, although to date little considered, phenomenon and can be considered as a viable response option in inclusive, integrated governance for biological invasions (**section 6.2.3.5**).

6.2.4 Integrated governance for biological invasions

Drawing on the approaches above and recognizing the relevance of multiple scales, sectors and levels of governance, "Integrated Environmental Governance" provides an option for improving the effectiveness of invasive alien species prevention and control because it focusses attention on the relationships between the necessary components of governance systems for biological invasions **(Box 6.5)**. In this way, context-specific application of integrated governance potentially simultaneously helps to address the challenges of fragmentation, complexity and information flow that are currently pervasive in governance

Box 6 5 **Integrated governance for biological invasions.**

Integrated governance for biological invasions consists of establishing the relationships between the roles of actors, institutions and instruments, and involving as appropriate all those elements of the socioecological system that characterize biological invasion and its management, for the purpose of identifying the strategic interventions needed to improve invasive alien species prevention and control outcomes.

for biological invasions (**section 6.2.2**). Coherent and better integrated policy regimes (**Glossary**) have been called for that aim to enable more effective and efficient policy outcomes, reduce policy conflicts, implementation delays, confusion and lack of clarity for stakeholders, wastage of resources and unanticipated outcomes in the complex contexts that characterize the governance and management of biological invasions (Riley, 2012; Vaas *et al.,* 2017). The definition of integrated governance for biological invasions below **(Box 6.5)** is in line with and built upon the concept of integrated environmental governance (Visseren-Hamakers, 2015; Visseren-Hamakers *et al.,* 2021)

Integrated governance, including for biological invasions, includes not only integration across sectors (so-called "nexus" in sustainable transitions literature; S. Díaz *et al.,* 2019; **Glossary**; **Chapter 1**, **Box 1.14**), but also a range of strategic actions and governance system properties characterize good governance for biological invasions (Weitz *et al.,* 2017). In other words, policy integration is only one part of the integration needed, and attention may also be given to the properties of the broader system that delivers invasive alien species policy (Leventon *et al.,* 2021).

A key part of the recognition of the need for integrated governance for biological invasions concerns the need for integration across the sectors that in some way intersect with the problem of invasive alien species – as either causal, affected or managing actors **(Figure 6.7)**, as discussed above. These sectors include environmental, human, animal and plant health (Hulme, 2020). This approach is referred to more broadly in governance literature as the "nexus approach" (S. Díaz *et al.,* 2019; Weitz *et al.,* 2017), and it "focuses on the relationships between different policies and sectors (e.g., agriculture, transport, environment) with the aim of coordinating across sectors without preferring one over the other in order to promote coherence" (Visseren-Hamakers, 2015). The intention of such integration is to improve policy coherence by "identifying synergies and trade-offs, optimizing policy options, and adapting governance arrangements" (Weitz *et al.,* 2017). This approach aims therefore to reduce undesirable outcomes for invasive alien species management that result from conflicting policy and interests across sectors. An example is the "One Biosecurity" approach: "an interdisciplinary approach to biosecurity policy and research that builds on the interconnections between human, animal, plant and environmental health to effectively prevent and mitigate the impacts of invasive alien species" (Hulme, 2020; **Glossary**).

While considering what needs to be integrated (e.g., research, sectors, policy) and how (e.g., stakeholder and Indigenous Peoples and local communities' inclusion, analysis, collective action) holds significant promise to achieve better outcomes for invasive alien species prevention and control, there are also limits to this approach that are important to recognize. The status of biological invasions and the most effective management approaches are to a large degree context-dependent, therefore, comprehensive and strongly centralized policy integration may be neither possible nor desirable (Herrick, 2019; Hoff *et al.,* 2019). New approaches or decision-making structures are not developed from a clean slate and can be strategically designed to strengthen or fill gaps in existing governance systems (Visseren-Hamakers, 2015).

Nonetheless, there is substantial evidence to suggest that a greater degree of policy integration would be beneficial in many instances (Lansink *et al.,* 2018; Smolarz *et al.,* 2016), and the benefits to building on existing policy settings have been highlighted (Trump *et al.,* 2018). To this end options for more effective invasive alien species policy, including integration where it is needed, include a number of desirable features, such as policy coherence and political legitimacy (Daviter, 2017; Herrick, 2019). Several tactics that enable this reform can be incorporated into invasive alien species strategies at national and other levels and sectors **(Table 6.7).** Other key considerations include external influence and dealing with the factors that influence integration beyond cross-sector relationships and policy (**section 6.2**). Finally, negotiation and building trust can improve the governance of biological invasions; addressing trade-offs and improving policy integration is a political process built on negotiation across stakeholders with different interests, values, and perspectives, which requires trust, ownership of the process, and learning (**section 6.4**).

Table 6 7 **Tactics to enable policy reform for invasive alien species policy.**

	Tactic	Expected benefit	Key references
1	Multidisciplinary to transdisciplinary research on invasive alien species policy regimes	Building robust and long-term resilience and the adaptive capacity of the governance systems for invasive alien species	(Daviter, 2017; Herrick, 2019)
2	Policy narratives to deal with the full continuous spectrum of service delivery or regulation, from prevention, eradication, control and restoration rather than treating each in isolation	Better integrated and effective policy regimes	(Daviter, 2017; Herrick, 2019)

Table 6 7

	Tactic	Expected benefit	Key references
3	Drawing on the full suite of adaptive and control-focused instruments as relevant **(Figure 6.8)**, including a combination of voluntary measures with regulatory and legislative frameworks	More comprehensive, effective and efficient governance for biological invasions	(Herrick, 2019; Primmer *et al.,* 2015; Shine *et al.,* 2000; Termeer *et al.,* 2010)
4	Inter-agency coordination to co-ordinate across policies and agencies and to monitor (stakeholder and Indigenous Peoples and local communities-wide or) government-wide activity	Increased efficiency and effectiveness of resource allocation and knowledge sharing	(Daviter, 2017; Herrick, 2019)
5	High autonomy for decision makers combined with strong, coherent, overarching policy	More efficient and targeted local solutions	(Vaas *et al.,* 2017)
6	Strategic and programmatic coordination that has adequate resourcing and authority to enable coordination	Improved effectiveness of implementation measures	(Daviter, 2017; Herrick, 2019)
7	Work towards intergenerational sustainability for invasive alien species by linking the consideration of ecosystem functions and process with management actions	Achieving environmental sustainability and political, stakeholder and Indigenous Peoples and local communities support	(Smolarz *et al.,* 2016)
8	Knowledge systems that enable sharing of information, concepts and arrangements across all stakeholders and scales	Improving learning to empower all stakeholders and Indigenous Peoples and local communities to manage invasive alien species	(Smolarz *et al.,* 2016; Staples & Hermes, 2012)
9	Creating space for multiple knowledge systems and experiences to encourage the recognition of different values	Building trust and social capital for effective collaboration and cooperation (collective action)	(Leventon *et al.,* 2021; McKiernan, 2018)
10	Implementing mechanisms for reviewing and monitoring policy effectiveness, including gathering data for "Response" indicators (following the Theory of Change, **section 6.2.1**) so that the success of management interventions can be assessed and fed into adaptive planning	Overcoming slow and inadequate implementation of policy	(McGeoch *et al.,* 2010; McGeoch & Jetz, 2019; OECD, 2019)
11	Integrating invasive alien species considerations into policies related to other environmental threats, including climate change	Policy that recognizes the inherent inter-dependencies of multiple forms of environmental change	(Smolarz *et al.,* 2016)
12	A focus and research on the relationships between policy instruments within and between sectors to determine what invasive alien species -relevant policy gaps exist, where policy conflicts occur, and how new policy can best complement existing policy – as the basis for a transition to integrated governance for biological invasions	Policy coherence, filling policy gaps and avoiding perverse incentives	(Visseren-Hamakers, 2015)

6.3 LEGAL AND REGULATORY OPTIONS

A broad array of international and national legal and regulatory instruments that directly or indirectly reference invasive alien species exist **(Table 6.8)**. These instruments aim to manage invasive alien species by preventing their introduction and spread and mitigating their impacts. They provide the formal rules upon which other policy instruments (e.g., economic, social; **Table 6.1**) can be framed and operated, and are also associated with multiple global, regional and national organizations. These instruments regulate or propose voluntary standards for the activities of different sectors (e.g., environment, production, extraction, health, trade and transport), often at different stages of the invasion process. This division of sectors, organizations, geopolitical scales and management by invasion stages highlights some of the main governance challenges of managing biological invasions discussed in **section 6.2**.

This section presents a suite of possible policy instruments to address the drivers and impacts of invasive alien species from a sectorial (**section 6.3.1**), geopolitical (**section 6.3.2**) and national (**section 6.3.3**) perspective. The options presented are brought together in **section 6.7**, where the need for alignment and

coordination between legal and regulatory instruments across sectors, geopolitical scales and invasion stages is described. Meeting these needs would solve the current significant gaps in coverage of regulations and/or standards targeting invasive alien species and help to implement integrated governance based on sharing efforts and commitment and understanding the specific role of all actors (related to the principle of shared but differentiated responsibility). A key finding of the present assessment is that there is a need for coordination between policy initiatives to promote free trade, protect animal, plant and human health, or address other drivers of biodiversity loss, such as climate change and land-use and sea-use change. The section also shows options to improve the efficiency and effectiveness of invasive alien species intervention efforts at the national level and their integration at a regional scale.

6.3.1 Legal and regulatory options at and across sectors

Legal and regulatory instruments from many interacting sectors deal with management of biological invasions, either directly or indirectly. This section presents and discusses the legal and regulatory instruments aimed at solving some of the main challenges in the five key sectors described in **Table 6.8**. Rather than describing specific sector-by-sector solutions, legal and regulatory instruments that apply, in many cases, to more than one sector are presented. The options described here focus on addressing four main governance challenges:

- fragmentation across sectors,
- externalities,
- conflicting interests and trade-offs, and
- hurdles to policy implementation.

Table 6 8 **Some of the international legal, regulatory and organization-based instruments relevant to invasive alien species by sector.**

Adapted from Burgiel (2015).

Sector	Activities	Examples of relevant legal and regulatory instrument	Type of instrument*
Biodiversity and environment	Conservation and natural resource management	CBD	Binding
		Ramsar Convention	Voluntary
		Bern Convention	Binding
		United Nations Framework Convention on Climate Change (UNFCCC)	Voluntary
		Protocol on Environmental Protection to the Antarctic Treaty (the Madrid Protocol)	Binding
Transport and trade	Movement of goods, sanitary and phytosanitary measures and border security	WTO	Binding
		IMO	Binding
		International Civil Aviation Organization (ICAO)	Voluntary
		IPPC	Binding
		WOAH	Binding
		World Customs Organization (WCO)	Voluntary
Production systems	Agriculture (silviculture, horticulture, livestock husbandry), aquaculture, and Living Modified Organisms[6]	IPPC	Binding
		WOAH	Binding
		FAO	Voluntary
		Cartagena Protocol on Biosafety	Binding
Extraction systems	Forestry and fisheries	FAO	Voluntary
Public health	Protection against public health threats	WHO	Voluntary
		One Health Joint Plan of Action	Voluntary

* Binding instrument refers to those where signatories have a legal obligation to implement and/or achieve their commitments

6. Living modified organisms are any living organism that possesses a novel combination of genetic material obtained through the use of modern biotechnology as defined by the Cartagena Protocol (Bail *et al.*, 2014).

6.3.1.1 Addressing fragmentation challenges

Building on the interconnections between different sectors (e.g., transport, human health, trade, agriculture and aquaculture, forestry and biodiversity) to overcome policy fragmentation would provide a pathway for the effective prevention of invasive alien species **(Figure 6.10)**. Such a pathway would benefit from a coordinated view of biosecurity across relevant agencies, and a clear definition of the roles and responsibilities of relevant national offices.

(1) Develop a coordinated approach to biosecurity across relevant agencies

A coordinated approach to biosecurity may help facilitate the export of products that otherwise would be subject to import restrictions in other countries. At the same time, it could protect agriculture, forestry, horticulture, fisheries, native biodiversity and human health. A coordinated view of biosecurity would mean blurring the lines between strong sectorial identities associated with specific international standards, individual economic sectors such as health, agriculture and the environment, specific research communities, and unique stakeholder and Indigenous Peoples and local communities involvement. Biosecurity can benefit from close collaboration between the various national agencies that oversee human health, trade policy, agriculture and aquaculture, forestry and biodiversity (CBD, 2012, 2018).

Efforts in the direction of cross-agency coordination have been proposed in reviews of existing biosecurity arrangements; for example, Australia's quarantine and biosecurity arrangements (CSIRO, 2022; Durant & Faunce, 2018) are at the core of the Great Britain Non-Native Species Strategy and its Secretariat **(Box 6.6)**. A broader coordinated biosecurity approach can be achieved through close dialogue between health, agriculture and environment sectors; global, national and local authorities; and natural and social sciences. For example, the One Biosecurity approach (Hulme, 2020) provides a framework to tackle multiple social and environmental challenges: climate change, increasing urbanization, agricultural intensification, human global mobility, loss of technical capability as well as public resistance to pesticides and vaccines. This framework can benefit policy development regardless of the type of invasive alien species

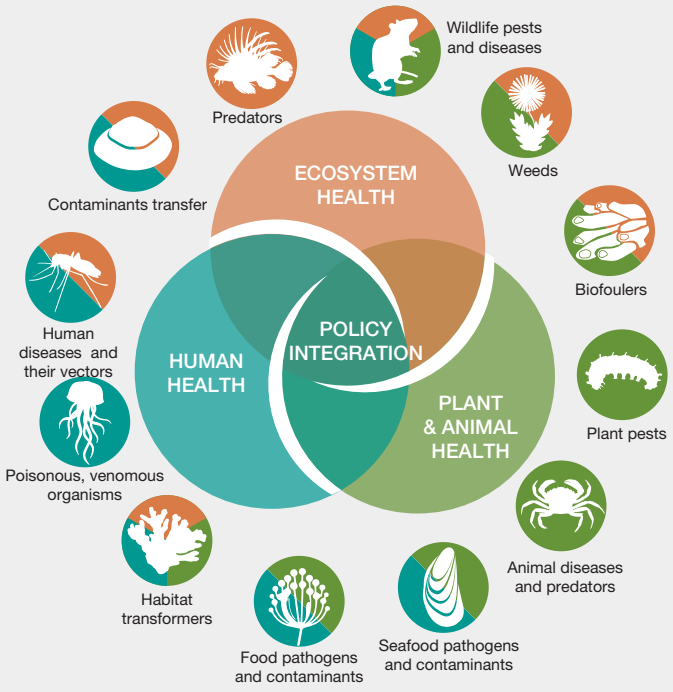


Figure 6 10 **A conceptual diagram of the links between different types of invasive alien species, human, animal, plant and environmental health that arise from the impacts of invasive alien plants, animals and pathogens, as described by the One Biosecurity approach (Hulme, 2020).**

Different types of invasive alien species will have different drivers, pathways and impacts, but their management and policy development aimed at prevention can all benefit from explicit recognition of the inseparability of human, ecosystem and plant and animal health and coordinated engagement by sectorial agents operating within each of those spheres.

presenting threats to nature, nature's contributions to people and good quality of life **(Figure 6.10)**.

A coordinated approach to biosecurity can be improved by additional capacity, including personnel, expertise and equipment. National agencies concerned with biological invasions may be able to build on efforts by agricultural and trade ministries to incrementally improve their sanitary and phytosanitary measures and border control systems. There may also be opportunities to fast-track development of these systems and address any knowledge and policy gaps by making relevant information available when and where it is needed across different offices. In many cases, knowledge sharing and adapting the practices and methods of countries with more advanced biosecurity systems could be an effective strategy in countries lacking biosecurity protocols (Hulme, 2021) and **section 6.6**. Finally, there may be creative opportunities to tailor capacity-building resources and materials currently offered by groups such as the World Bank, the IPPC, the WOAH **(Table 6.8)**, the WCO, regional development banks and national or regional research and development organizations.

(2) Clearly define roles and responsibilities across existing national offices within legal and regulatory instruments

Risk assessments are the most common approach to prevent the introduction of potentially harmful alien species from imports (**Chapter 5**, **section 5.2.2.1.e**), and are an essential component of any legislation enforcing regulations of trade. In fact, as explicitly stated by the WTO SPS Agreement, countries have the legal right to take proportional measures affecting trade based on the application of scientific principles. Deciding which governmental authority is responsible for assessing the risks of specific imports is important for preventing unwanted introductions. A clear definition of the roles and responsibilities of all agencies involved in the prevention of alien species introductions can help to devise effective management strategies (Hewitt *et al.,* 2006). Moreover, these roles and responsibilities can be supported by legal and regulatory frameworks that allow governments to execute the assigned tasks (Hewitt *et al.,* 2006). The questions in **Box 6.6** can help to guide governments to identify the most appropriate authority, and to strengthen the tools and methods for decision-making (as discussed in **Chapter 5**, **section 5.2.2**). These decisions could focus on defining the appropriate level of protection, and trade-offs between good quality of life benefits of the import and potential impacts on biodiversity. It is important to highlight that although one authority might be considered responsible for assessing the potential impact of an import, continuous communication and coordination between government agencies could ensure that all possible risk dimensions are taken into consideration.

Box 6 6 **Governance and management questions to guide decisions on import proposals for aquaculture, horticulture, or silviculture species.**

Adapted from Hewitt *et al.* (2006).

1. Does the government permit the importation of alien species?
2. Will any new species imports be allowed for production purposes?
3. Has an adequate risk assessment been conducted to support the decision to import the new species and provisions for managing potential harm?
4. Under what national regulation(s) will the import of a new species occur?
5. Which government agencies are responsible for management of these regulations?
6. Will these new species be allowed for uncontrolled release, within controlled or quarantine facilities?
7. Will the responsibility for managed species (e.g., in aquaculture/horticultural) be different from wild (e.g., wild, feral, or released species) populations?
8. Who will be responsible for the importation (e.g., private individual, research agency/university, industry, or government)?
9. Under what legislative arrangements will release into either a managed facility or the natural environment occur?
10. Who will be responsible for managing the release (e.g., private individual, research agency/university, industry, or government)?
11. Are there appropriate monitoring systems in place to detect and manage accidental releases in the environment?
12. Could neighbouring jurisdictions potentially be affected, and if so, are communication pathways in place to manage the risk?
13. Will neighbouring countries be involved in the decision-making process?
14. Do emergency response measures exist, including identification of the responsible authorities, in case of unforeseen negative impacts?

6.3.1.2 Addressing the indirect costs of biological invasions to uninvolved third parties: externalities

The overarching goal of the policy options presented in this section is to incorporate the negative impacts of invasive alien species into the social or economic context responsible for their introduction and spread. Such an approach would align the private, environmental and social costs of invasive alien species, so that trade-focused decisions take into consideration the environmental needs of society. It would ensure that all responsible government agencies are involved in attributing associated costs and that prices carry all the relevant information. This option would benefit from clear delineation of the environmental jurisdiction of non-environmental multilateral agreements and defining liability and redress from the negative impacts of invasive alien species on nature, nature's contributions to people and good quality of life.

(1) Delineate the environmental jurisdiction of trade agreements, so that the mandates of multilateral environmental agreements are enforceable

The tug-of-war between the philosophical underpinnings of biodiversity centred (grounded on the precautionary approach) and trade-related multilateral agreements (grounded on the evidence of adverse effects of an introduction) creates a conflict between trade and the environment (Stilwell & Turk, 1999). One way to avoid such conflict in the context of biological invasions is for governments to proactively define the relationship between trade and environmental centred agreements when negotiating multilateral environmental agreements. As discussed in Stilwell & Turk (1999), defining this relationship should not rely on exemptions ("saving clauses") in multilateral environmental agreements. Rather, agreements would better aim to establish a mutually supportive relationship between trade and the environment. Determining when the provisions in one of these two sets of agreements should supersede the other would help to internalize the externality of alien species impacts. It would also enhance policy coherence between multilateral agreements on trade and the environment, making these mutually supportive in favour of sustainable development (OECD, 2020). Specifically, this could bring about balanced and effective multilateral agreements for this transboundary and global environmental problem without the fear of trade barriers being invoked (Stilwell & Turk, 1999). This clarity would also help preserve the integrity of the multilateral trading system, which is increasingly criticized for its tendency to override social and environmental policies (European Commission, 2021). Likewise, it would address the view of social and environmental agreements as attempting to override multilateral trading rules (European Commission, 2021). Overall, such policy integration would also reduce the tendency and need to resort to unilateral trade measures, which would result in a lack of coordination and collaboration across jurisdictions.

(2) Defining liability and redress from the negative impacts to biodiversity of invasive alien species in multilateral and national legal and regulatory instruments

Invasive alien species can be viewed as a form of "self-regenerating pollution" (De Klemm, 1996). A "legal personality" (**Glossary**) or entity could therefore be regarded as liable for the damages caused from their involvement in the introduction of an invasive alien species. Preamble 33 of European Union Regulation 1143/2014 affirms that Member States should impose effective, proportionate and dissuasive sanctions for infringements, considering the nature and gravity of the infringement, the principle of recovery of the costs and the polluter pays principle. The same legislation, at art. 21 on cost recovery, says that "in accordance with the polluter pays principle … Member States shall aim to recover the costs of the measures needed to prevent, minimize or mitigate the adverse impact of invasive alien species, including environmental and resources costs as well as the restoration cost." However, the idea of liability and reparation for the impacts of an invasive alien species is missing from many multilateral environmental agreements. One notable exception is the Bern Convention which makes a formal recommendation about liability. Another example is the Convention on Civil Liability for Damage Resulting from Activities Dangerous to the Environment in Europe (Council of Europe, 1993) that specifies liability for genetically modified organisms or micro-organisms that present a significant risk for humans, the environment, or property.

Different objectives and guiding principles across legal and regulatory instruments raise complex questions about how liability for biological invasions can be assigned; and how liability can be enforced under the current state of international law. The use of environmental liability directives such as the Principle of Polluter-pays (for example, EU Directive 2004/35/CE) or nuisance laws (Pidot, 2005) provides one pathway to incorporate liability and redress provisions into the current multilateral environmental agreements. In these cases, damages are recognized as any unwanted change in protected species and natural habitats, water resources and/or soils (**Chapter 5**, **section 5.3.2**): namely, negligence or intentional actions of legal persons or entities involved in activities resulting in "environmental damage". In the context of transnational impacts, the best approach is that national legal and regulatory frameworks reflect obligations under international law and emphasize transboundary cooperation and collaboration concerning management of biological invasions, including liability for harm.

Given the nature of biological invasions, enforcing environmental liability would require shifting the burden of proof from the prosecution to the defendant(s) (Kramer, 2005; Pidot, 2005). Under such a regime, the prosecution would only have to demonstrate objective facts about the presence of an invasive alien species associated with a given activity of a legal person(s) or entity(ies); then the defendant(s) would need to prove the resulting invasion was not the product of negligence (Secretariat of the CBD, 2001). These proofs would be provided by all parties that received some form of financial benefit from the transport, sale and/or introduction of the species liable for some part of the harm (Secretariat of the CBD, 2001). Reframing who should be the target of punitive proceedings has the potential to develop a culture of accountability and responsibility, focused on encouraging voluntary compliance and implementations of best practices, though it is important that punitive actions are maintained as a potential last resort (Kramer, 2005; Pidot, 2005).

6.3.1.3 Addressing conflicting interests and trade-offs

Balancing the interests of multiple sectors and activities can be achieved through the development of legal and regulatory instruments, and reduce inconsistencies and misalignment in the objectives of legal and regulatory instruments. This approach could remove perverse incentives and, for example, encourage the transition to native species (**Glossary**) in production systems, stop the promotion of alien species as a tool to reduce poverty and increase food security, and increase the awareness of invasive alien species problems in disaster relief and assistance programmes.

(1) Removal of perverse incentives in sector-specific legal and regulatory instruments

Legal and regulatory instruments that promote trade, agriculture and aquaculture, infrastructure management and tourism can also facilitate invasive alien species introductions (**Chapter 3**, **section 3.2.5**) and exacerbate their impacts on biodiversity (**Chapter 4**, **section 4.3**). The removal, phase out, or reform of these incentives harmful to biodiversity is one of the Kunming-Montreal Global Biodiversity Framework targets (Target 18). As discussed by Herrick (2019) and Lodge *et al.,* (2006) aligning economic, social and environmental goals is the first step towards resolving perverse incentives (CBD, 2011). Such alignment can be achieved through careful evaluation of the trade-offs between policies with well-intentioned objectives, for example those aiming to improve good quality of life and nature's contributions to people but that promote the use of invasive alien species to do so. **Figure 6.11** showcases some examples of such perverse incentives. There are existing policy guidelines relevant to this topic (such as the European Union Green Paper on the Reform of the Common Fisheries; Commission of the European Communities, 2009), and new ones could be developed that focus on addressing specific perverse incentives. The analytical and policy guidance tools developed by the Organisation for Economic Co-operation and Development (OECD; OECD *et al.,* 2007; Sovacool, 2017) and the United Nations Environment Programme (UNEP; Morgan, 2008; Sovacool, 2017) are also valuable tools to start evaluating and addressing the possible biodiversity impacts of current and future legal and regulatory instruments.

Two factors could be considered to remove perverse incentives associated with activities that contribute to biological invasions. First is the resistance to substantive reform. In many cases, removing or modifying a policy can raise legitimate concerns about the economic consequences and the political capital cost of such changes. This is exemplified by the criticism of several countries of CBD COP decision VI/23 (CBD, 2002). In their view, Guiding Principle 7 (which advises member states to "implement border controls and quarantine measures, for alien species… based on a risk analysis of the threats posed by alien species and their potential pathways of entry") could be used as a tool to implement disguised trade barriers, thereby contravening the WTO SPS Agreement. A second factor to consider is the scale (spatial and temporal) at which proposed changes could potentially have an impact. In many cases, policy changes that can prevent invasive alien species introductions or reduce possible invasion drivers will have a direct, short-term economic and social cost for local communities, although communities would benefit from such changes in the long term. Identifying, understanding and adequately responding to the possible short-term social impacts of activities that promote the use of invasive alien species is one of the most challenging aspects of reforming policy instruments.

In addition to the examples shown in **Figure 6.11**, the development of a carbon sequestration economy could facilitate introductions of alien species (**Chapter 3**, **section 3.2.5**). This could take place *via* tree plantations through initiatives like Reducing Emissions from Deforestation and forest Degradation (REDD; Harvey *et al.,* 2010), national and multilateral initiatives on the use of biomass for energy production (i.e., EU, 2018; Jonsson *et al.,* 2021), and other restoration strategies (Brundu *et al.,* 2020) involving invasive, or potentially invasive, alien species. Tree planting is at the core of many national and regional climate strategies (i.e., carbon neutrality commitment by the European Union, China, United States, South Africa, Japan, South Korea and Canada; Climate Action Tracker, 2020). However, the most frequently used species in forestry plantations are trees from the genera *Pinus, Eucalyptus* and *Acacia* species. Though these species have traits that make them suitable for relatively rapid afforestation, they are also potentially highly invasive (Doughty, 2000; Eldridge *et al.,*

(A) Agriculture

Chemical control of alien agricultural pests has generated great concern by virtue of its non-target impacts on species of conservation concern. Carson (1962) raised this issue in her book that helped launch the environmental movement, and use of other broad-spectrum insecticides has led to similar impacts.

(B) Aquaculture

There are several instances where unintentional introductions may be associated with cultured target species; one of these being introduction of *Sargassum muticum* (wire weed) with oyster imports.

(C) Public health

The use of broad-spectrum insecticides to control introduced mosquitoes that vector human diseases, such as DDT, affected many bird species, including those of conservation concern, through eggshell-thinning. It also exacerbates pesticide resistance.

(D) Forestry

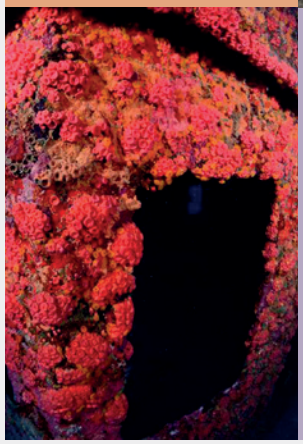
The forest-based industries and/or the energy production sector can be impacted by biological invasions. An example is *Eucalyptus globulus* (Tasmanian blue gum), which has invaded many forestry adjacent sites in North-West Spain.

(E) Infrastructure management

Road construction and roadside maintenance have often fostered invasion by non-native plants. Increasing establishment of mobile and immobile artificial structures (e.g. ships, barges, coastal defences, artificial reefs, offshore platforms) and canals play major roles in transmission, establishment and spread of aquatic non-native species.

(F) Military facilities

Midway Atoll was the site of a U.S. Naval Air Station from 1940 through 1996. The invasive plant *Verbesina encelioides* (golden crownbeard) was first observed in 1955 but was maintained at low abundance by intensive road and landscape maintenance. A shift in the 1990s to greatly reduced mowing and herbicide use triggered massive growth of this plant to the detriment of nesting seabirds, especially albatrosses.



(G) Tourism

National actions to promote local tourism (e.g., artificial reefs) in marine protected areas. Brazil's Tourism Ministry launched a plan to sink 1200 scrapped ships, trains, and airplanes, most of them inside marine protected areas, supposing that they will promote diving tourism business. Artificial reefs, such as those that would be created by sinking those vehicles, are used by invasive alien species (e.g., *Tubastraea* spp. (sun corals)) as stepping-stones to natural reefs, causing ecological, social, and economic deterioration.

(H) Biomass

Prosopis spp. (mesquite) are a group of species native to Central and South America which have been introduced in Australia, Asia, and Dryland Africa for fuel wood, fodder, to improve soils and reduce erosion. After the demand for *Prosopis* crashed, many plantation were abandoned without management or eradication. As a result *Prosopis* has become a major problem, particularly in Africa. It has severely impacted traditional livelihoods of pastoral communities.

Figure 6 11 **Examples of perverse incentives where actions aimed at promoting an activity fail to take into account the existence of environmental externalities.**

Examples present cases where (a) agriculture (Carson, 1962; Herms & McCullough, 2011), (b) aquaculture (Engelen *et al.,* 2015), (c) public health (Carson, 1962; Walker *et al.,* 2003), (d) forestry (Calviño-Cancela & Rubido-Bará, 2013), (e) infrastructure management (Galil *et al.,* 2017; Mineur *et al.,* 2012; Skultety & Matthews, 2017), (f) military facility management (Taylor *et al.,* 2020), (g) tourism (Miranda *et al.,* 2020) and (h) biofuels (Pasiecznik, 1999) can promote biological invasions. Photo credits: (a) James H. Miller, USDA Forest Service, Bugwood.org – under license CC BY 3.0 US / (b) Graça Gaspar, WM Commons – CC BY-SA 3.0 / (c) LSIS Helen Frank, WM Commons – Public domain / (d) Ignacio Amigo – CC BY 4.0 / (e) Rept0n1x – Walk to Lunt (102), WM Commons – CC BY-SA 2.0 / (f) Forest & Kim Starr, WM Commons – CC BY 3.0 US / (g) Paula Raposo – CC BY 4.0 / (h) Thamizhpparithi Maari, WM Commons – CC BY-SA 3.0.

1994; D. M. Richardson & Rejmanek, 2004). While not invasive, *Elaeis guineensis* (African oil palm) plantations have been promoted as a climate mitigation strategy, yet they have limited biodiversity and conservation value (Harvey *et al.,* 2010). Therefore, not considering fundamental environmental values, including safeguarding biodiversity in climate mitigation initiatives, can result in serious negative ecological consequences. Examples of impact include biotic homogenization (**Glossary**, Olden *et al.,* 2004), genetic swamping (R. C. Barbour *et al.,* 2010) and altered ecosystem processes (Simberloff *et al.,* 2009). Moreover, the escape of these plantation species can become costly to manage and lead to significant biodiversity losses (D. M. Richardson & Rejmanek, 2004).

(2) Encourage the transition to native species in production systems

Reducing the dependence of the still growing aquaculture, horticultural and silvicultural sectors on alien species is one of the most pragmatic approaches to reduce translocations of problem species within and across national borders. There are options to replace some cultivated alien species with native species (e.g., Jones Jr & Foote, 1991; Pérez *et al.,* 2003; van Heezik *et al.,* 2012). Mainstreaming this perspective can be done through technical and policy developments that promote potential candidate native species that are preferred by their respective communities and local consumers. Nonetheless, it is important to highlight that alien species constitute as much as 75 per cent of the species used for consumption (Palacios, 1997), and that these constitute the cornerstone for the economic activities of multiple communities. Therefore, such transition needs to consider the possibility of alien species replacement to fulfil food security and economic needs, with fisheries and forestry species more frequently invasive than terrestrial food crops (De Silva *et al.,* 2009; FAO, 2019).

Some alien species used in many production systems are causing significant losses in performance, primarily from inbreeding (E. O. Wilson, 1999). Rather than replenishing the stocks of these alien species with fresh germplasm obtained from their natural range, policy and voluntary codes of practice could promote the development of viable and profitable culture techniques for suitably selected native species. The pangasid fish culture (*Pangasianodon hypophthalmus* (sutchi catfish)) in the Mekong Delta is a successful example of the viability of gradually reducing the dependence on alien species *via* the replacement by native species (De Silva *et al.,* 2009; Nguyen, 2007). The aquaculture production of *Piaractus mesopotamicus* (small-scales pacu) in Argentina is another example of the successful use of native species to address decreases in capture fisheries (Quirós, 1990). *Piaractus mesopotamicus* production is now the second largest aquaculture species-based production in Argentina (FAO, 2016). However, success is mixed across examples of shifts to native species in production systems, with shifts not being feasible in aquaculture in Indonesia, Malaysia and Thailand, but underway in some cases in India and Bangladesh (De Silva *et al.,* 2006, 2009). Similar contrasting trends have been reported in aquaculture in Europe (Turchini & De Silva, 2008).

In the case of silviculture, options for the replacement of invasive alien with native species seem limited in commercial forestry with the most productive forestry species being alien (D. M. Richardson, 1998; D. M. Richardson & Higgins, 1998). In the Galapagos, where other invasive alien species (*Centrolobium paraense, Juglans neotropica* (andean walnut), *Swietenia macrophylla* (big leaved mahogany) and *Tectona grandis* (teak)) are established, conservation authorities are encouraging the replacement of invasive alien timber species with non-invasive alien timber species (*Cedrela odorata* (Spanish cedar) and *Cordia alliodora* (Ecuador laurel)) and horticultural species (*Psidium guajava* (guava), *Cinchona pubescens* (quinine tree); Richardson, 1998).

(3) Stop the promotion of alien species as a tool to reduce poverty and increase food security

Alien species are the cornerstone of many aquacultural practices aimed at improving food security. Examples are alien tilapia (*Coptodon* spp., *Oreochromis* spp. and *Sarotherodon* spp.), salmonids (*Salmo trutta* and *Oncorhynchus mykiss*) and oysters (*Crassostrea* spp., *Ostrea* spp. (flat oyster), *Argopecten* spp.; De Silva, 2012; Paini *et al.,* 2016; McBeath & McBeath, 2010). This also been the case for silvi/agro-cultural initiatives aimed at reducing poverty, where species such as eucalypts and *Leucaena leucocephala* have been introduced in Southeast Asia. Grasses and legumes from Australia, South Africa and North America have been introduced in experimental farms near Santa Cruz (Bolivia) and *Prosopis juliflora* (mesquite) has been introduced in Africa **(Figure 6.11)** for fuel-wood for the rural poor (Murphy & Cheesman, 2006; **Chapter 4**, **Box 4.9**). These species can escape production environments and have adverse impacts on biodiversity and ecosystems (**Chapter 3**, **sections 3.2.5** and **3.3.1.1**). A first step to avoid this problem could be a strategy shift by development assistance organizations to embed the preferred use of native species into their codes of practices. Exploring viable native alternatives as primary species for human consumption or as animal feed is an option for such organizations. This shift will benefit from being coupled with national policy that promotes a culture of native species cultivation valued by Indigenous Peoples and local communities.

However, the implementation of a “native species”-centred approach would require careful consideration in each case. For example, it is critical to consider if native species can provide viable alternatives to assure food security for ever

increasing human populations, especially in rural populations of developing countries (De Silva *et al.,* 2009; Murphy & Cheesman, 2006; Shackleton, Richardson, *et al.,* 2019). It would be important to consider socioeconomic conditions, as well as the views and needs of Indigenous Peoples and local communities, so that good quality of life is not adversely affected. This is clearly the case for alien tilapias (*Coptodon* spp., *Oreochromis* spp. and *Sarotherodon* spp.) in China, Indonesia, the Philippines and Sri Lanka, where they play a major role in subsistence aquaculture systems by providing a relatively cheap source of animal protein, as well as considerable export income (De Silva *et al.,* 2004, 2009); simply put, shifting to a less productive native species may not be feasible.

(4) Develop guidance documents and codes of practice to reduce pathway risks for disaster relief and assistance programmes

The lack of awareness of the possible problems caused by invasive alien species in international development programmes has made disaster relief and assistance an major invasion pathway (Murphy & Cheesman, 2006; **Chapter 3**, **section 3.2.2.2**). Specifically, the invasive alien species problems created by international disaster relief and assistance programmes arise unintentionally from activities inspired by humanitarian motives. Many anecdotal reports (summarized by Murphy & Cheesman, 2006) link invasive alien species to these programmes (**Chapter 3**, **section 3.2.2.2**). As the negative effects of alien species (un)intentionally introduced *via* this pathway can be long lasting and outweigh positive impacts, increasing this awareness is important.

The most efficient line of defence to identify possible invasive alien species in aid packages might be developing biosecurity protocols, voluntary codes of practice and risk assessment protocols focused on preventing (un) intentional introduction in these programmes. Addressing the problems that have resulted from invasive alien species (un)intentionally introduced by past international assistance and aid /relief activities could be a priority for all associated stakeholders. However, conflicts of interest may arise where an environmentally damaging species is contributing to local livelihoods (as reviewed in Shackleton, Shackleton, *et al.,* 2019; **Chapter 5**, **section 5.6.1.2**). Therefore, careful consideration is necessary of the trade-offs between reductions in nature and good quality of life benefits due to invasive alien species impacts and the immediate needs of vulnerable populations.

6.3.1.4 Addressing implementation challenges in key areas

Effective management of biological invasions can be promoted in multilateral and national legal and regulatory instruments by including early warning systems (**Chapter 5**, **section 5.5.2**) in all environmental legal and regulatory instruments; considering all alien species as possible environmentally hazardous living organisms; developing strategies to regulate cross-border e-commerce (**Glossary**); increasing awareness of and improved compliance with (voluntary) codes of practices; and incorporating prevention and control of invasive alien species into protected areas and island management plans.

(1) Include early warning systems for invasive alien species into multilateral environmental agreements and national legal and regulatory instruments

Although biodiversity-related policy instruments dealing with invasive alien species have generic surveillance provisions (e.g., the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the CBD, Article 29 and subsequent decisions; Cartagena Protocol, Article 17; International Treaty on Plant Genetic Resources for Food and Agriculture Article 17.2, or the Ramsar Convention on Wetlands, Articles 3(2), 4(1), 4(3), 6(2) (InforMEA, 2021)), no instrument has a direct requirement for monitoring or the development of early warning systems. The need to develop effective global early warning and rapid response systems has been stated as a priority action by the CBD COP (decision IX/4 “In-depth review of ongoing work on alien species that threaten ecosystems, habitats, or species” and by the “Charter of Syracuse” on biodiversity, adopted at the G8 Environment Ministers Meeting (22–24 April 2009, Syracuse, Italy). Early warning and rapid response systems for invasive alien species can detect the occurrence of new invasive alien species, supported by activities to identify new species correctly and acquire all related information (European Environment Agency, 2010b).

The lack of clear provisions on early warning systems is due to the need for cross-national integration of effort and standards for effective surveillance, which has proven difficult for biodiversity policy instruments (Hulme, 2021). A notable exception that incorporates monitoring provisions is the Bern Convention. Monitoring and early warning system provisions is also part of many management recommendation documents, such as guidelines by the IUCN (IUCN, 2000; Tye, 2018) and the Council of Europe (Genovesi & Monaco, 2013). Monitoring and early warning system provisions could be incorporated into multilateral environmental agreements and national policy instruments. For these provisions to be effective, they could encourage participation across government and non-government agencies, the scientific community and the general public. Such engagement could, for example, be *via* a complaint system to a dedicated national authority, which has proven to be a successful monitoring tool for the Bern Convention (C. L. Díaz, 2010). Also, similarly to the reporting mechanism

under the UNFCCC, periodic reporting on the numbers and identity of invasive alien species by member states could be part of the provisions of multilateral environmental agreements. An international biosecurity convention organization (similar to the secretariat of the Convention on the Conservation of Migratory Species of Wild Animals (CMS)), if established, could implement a global surveillance and monitoring network to provide early warning of new threats (Hulme, 2021). Creating an international warning system is a large task, but there is already ongoing research in this direction (Latombe *et al.,* 2017; Pagad *et al.,* 2018; Essl, Lenzner, *et al.,* 2020).

(2) Inclusion of all invasive alien species as environmentally hazardous living organisms

Three areas central to biosecurity are: the management of risks associated with the accidental introduction of pests and diseases with food and agriculture, the introduction and release of genetically modified organisms and their products, and the deliberate introduction and management of invasive alien species and genotypes (FAO, 2003; **Chapter 3**, **sections 3.3.1** and **3.3.5.2**). Many biosecurity protocols do not cover "hitchhikers" or contaminants (e.g., spiders in produce, ants in taro plants), making the case for a broader definition of hazardous organisms, one that includes possible alien species that may affect the environment, the economy and/or human health (such as the New Zealand Import Health Standards that include provisions for hitchhikers and contaminants).

In addition to a broad definition of "hazardous organisms" in trade-related biosecurity protocols, clear and accurate labelling for consignments of all living organisms being transported is needed to prevent invasion. Labelling can be supported by regulated species lists with prohibited (strict approach) or permitted (lenient approach) species listed by jurisdiction and supported by import risk analyses. This protocol could be accompanied by handling protocols that promote environmental safety during transport. Adequate labelling needs to be developed and implemented through an efficient exchange of information between vendors and national authorities. The WCO has developed cross-border e-commerce frameworks (WCO, 2018) and technical standards (WCO, 2019) for this purpose, focusing on the need for electronic data to manage the risks of cross border movements of goods, and has been asked at COP15 of the CBD to look specifically at the question of e-commerce and invasive alien species (CBD, 2022c). Through the exchange of advanced electronic data, and considering all traded species as hazardous organisms, national authorities can ensure compliance with regulatory requirements. Furthermore, the use of detailed and accurate labelling of consignments would make exporters active participants in biosecurity and responsible for clean trade (**Glossary**, Hulme, 2021).

The UN Economic and Social Council's Sub-Committee of Experts on the Transport of Dangerous Goods will consider including environmentally hazardous living organisms in chapter 2.9, class 9, of the United Nations *Recommendations on the Transport of Dangerous Goods – Model Regulations*,[7] at its upcoming session in 2023, taking into account the risk of unintentional introduction of invasive alien species, including pathogens. This could be a significant step forward if governments are willing to accept it.

(3) Develop and raise awareness of codes of practices and standards and other mechanisms to regulate cross-border e-commerce

The rise of e-commerce contributes to invasive alien species spread (**Chapter 3**, **section 3.2.3.1**), and is becoming an increasingly critical biosecurity concern (Ricciardi *et al.,* 2017; **Chapter 5**, **section 5.3.1.1**). However, the online trade of living organisms is poorly regulated (Lenda *et al.,* 2014; Mazza *et al.,* 2015). Also, the high level of anonymity in online trade can circumvent accountability and taxes. Individuals and small companies that sell through the internet may not be legally registered and often do not disclose their specific location of operation. As a result, consignments of regulated articles can be imported into a country without any effort to meet the phytosanitary requirements of the receiving country (Derraik & Phillips, 2010; Keller & Lodge, 2007; Morrisey *et al.,* 2011). Buyers and sellers in the plant and animal trade may be ignorant or misinformed on potential dangers and biosecurity regulations, or may incorrectly identify their products (Giltrap *et al.,* 2009; Walters *et al.,* 2006). As such, national lists of regulated species are more important than ever. For example, the European Union, through the European Union Regulation 1143/2014, has adopted a List of species of Union Concern that are banned from import into the Union, and for which there is a general obligation to eradicate or control when recorded in the territory of a member state. The list is regularly updated. In 2004, Japan adopted an Invasive Alien Species Act that includes a list of regulated species.

Based on these lists, voluntary codes of conduct for e-commerce platforms could be developed as cost-effective approaches to address the trade-off between the economic benefits of e-commerce and the risk of environmental harm from the scope of these species (Monaco & IUCN Invasive Species Specialist Group, 2021; Shackleton, Adriaens, *et al.,* 2019). Specifically, the adoption of voluntary codes of conduct could prevent sales and auctions of species into countries where they are regulated and improve correct labelling of traded species. These conduct codes could

7. United Nations publication, Sales No. E.19.VIII.1.

stimulate e-commerce platforms to self-regulate by screening their own listings for species of concern and proactively complying with countries' invasive alien species laws, requiring sellers on online platforms to provide information on the species they sell. At a minimum, this information would include taxonomy, a record of potential invasiveness of these species, and appropriate measures that a buyer could use to prevent a species escape or release. Clear labelling of consignments, combined with lists of prohibited or permitted organisms, is perhaps the best way to prevent environmental harm without imposing major constraints on e-trade.

Such voluntary guidelines are in the process of being implemented for endangered and threatened species trade by the world's leading technology companies, including e-commerce and social media companies (e.g., Alibaba, eBay, Facebook, Google, Instagram, Microsoft, Pinterest, etc.). One example of a related effort is the work by the Coalition to End Wildlife Trafficking Online.[8] It is a partnership between environmental organizations such as Trade Records Analysis of Flora and Fauna in Commerce (TRAFFIC), World Wildlife Fund for Nature (WWF) and the International Fund for Animal Welfare (IFAW) with companies from across the globe to reduce wildlife trafficking online. Expanding these standards to include invasive alien species would help reduce introductions of invasive alien species through e-commerce.

The effectiveness of voluntary guidelines, codes of conduct and standards can be improved through the development of an efficient information exchange system accessible to all parties involved in trade and transport. At COP15, CBD parties considered measures on e-commerce and associated risks of invasive alien species (CBD, 2022c). One of these measures is considering the implementation of a single-entry system that facilitates the sharing of standardized information and documents with a single-entry point (i.e., a "Single Window approach") to fulfil all import, export and transit-related regulatory requirements.

(4) Increase awareness, participation and compliance with (voluntary) codes of practice for the translocation and exploitation of invasive alien species

Increasing governmental support for deregulation combined with industry opposition to restrictive legislation has led to a progressive emphasis on corporate responsibility and voluntary codes of practices worldwide (Sethi, 2011). Several activity-specific voluntary codes of practices have been developed to address the management of invasive plant species by the ornamental nursery industry (Baskin, 2002; Heywood & Brunel, 2009 and **Box 6.7**), aquaculture and forestry. Similar codes of conduct have been developed in Europe for several relevant activities, including boating, botanic gardens, hunting, international travel, pets, recreational fishing, zoological gardens and aquaria (such as the European code of conduct on hunting and invasive alien species, and other available at EASIN (2021)). These codes of practice provide practical and concise guidance in establishing common standards of good practice and responsible attitudes and behaviours for use of alien species in production activities. Their recommendations are intended to be complementary, not replace, the binding obligations embedded into national legislation and action plans that regulate any activity that transports, sells, or uses alien species.

The effectiveness of voluntary codes of conduct has limits but can be a valuable part of integrated systems to reduce the risk of invasive alien species. In fact, several codes of practice on invasive alien plants are in use throughout the world. Codes of practices on invasive alien species have two main goals: (1) to reduce deliberate introductions of invasive plants and (2) to increase the level of awareness-raising (Halford *et al.,* 2014). For example, the European and Mediterranean Plant Protection Organization (EPPO) standard PM 3/74(1) provides guidelines on the development of a Code of practice on horticulture and invasive alien plants (EPPO, 2009).

(5) Policy to support incorporation of management of biological invasions into protected area management plans

The designation of parcels of land- or seascapes as protected areas does not confer immunity from the effects of invasive alien species, and the invasion of protected areas erodes the maintenance of species diversity and natures contributions to people (e.g., terrestrial plants, Foxcroft *et al.,* 2013; Liu *et al.,* 2020; and marine systems, Gallardo *et al.,* 2017; Giakoumi *et al.,* 2019). This has become a concern at an international level, with many global conventions, policies or strategies focused on the threat of invasive alien species in protected areas in development (Foxcroft *et al.,* 2017; Shine *et al.,* 2000). The designation of protected areas will likely increase as a result of the Kunming-Montreal Global Biodiversity Framework adopted at COP15 of the CBD in late 2022, which clearly encouraged governments to increase protected areas on land and in water by restoring (Target 2) or protecting (Target 3) at least 30 per cent of terrestrial, inland water and of coastal and marine areas.

Due to the importance of protected areas, policy instruments could be developed to elevate protected areas to priority invasive alien species management sites, using a site-based management strategy (**Glossary**; **Chapter 5**, **section 5.3.1.3**). The development of such instruments may lead to the formalization of alien species management plans into the protected area management planning process.

8. https://www.endwildlifetraffickingOnline.org/

Box 6 7 The way forward for ornamental horticulture and invasive alien plants: How to reduce risks and achieve sustainability?

Ongoing innovation, cultivation and introduction of new plants has been considered critical to the survival and profitability of the horticultural sector, and can result in the ongoing introduction of alien species (Seaton *et al.,* 2014). Ornamental horticulture fosters plant invasions in a number of ways (Culley *et al.,* 2011). First, it often involves multiple introductions which include both the initial introduction as well as the subsequent sale and distribution of cultivated individuals through supply chain, retail centres, mail order catalogues, and over the internet (Culley *et al.,* 2011). Second, selective breeding may unintentionally favour traits, such as rapid growth, rapid seed germination, drought tolerance and disease resistance, that can enhance spread and invasive potential. Third, ornamental horticulture may promote invasiveness through commercialization of cultigens (plants known only in cultivation; Spencer & Cross, 2007). Although some may be self-sterile, different cultigens planted together may cross-pollinate and form viable fruit that is dispersed into natural areas. This has already been documented, for example, in *Pyrus calleryana* (callery pear) and *Lythrum salicaria* (purple loosestrife; **Figure 6.12**; Culley *et al.,* 2011; Culley & Hardiman, 2007, 2009).

To prevent further plant invasions resulting from ornamental horticulture, countries could commit to promote the inclusion of specific guidelines for the ornamental horticulture sector and supply chain, within the framework of national strategies on biological invasions and within related national policy (for example those relevant to biodiversity, SDGs, sustainable agriculture and forestry). As discussed by Hulme *et al.* (2018), closing this plant invasion pathway can be achieved by government-industry agreements to fund effective pre-and post-border weed risk assessments. This can be supported by widely adopted industry codes of practices. One example is the Code of Conduct for Invasive Alien Trees (Brundu & Richardson, 2016), which complements other European existing codes of practice dealing with horticulture and botanic gardens (Heywood & Sharrock, 2013). Codes of practice help producers and consumers make informed choices and help to target public education needed about horticultural invasion risks. For example, Green Lists of non-native ornamental species that have been assessed as having a low risk of escaping cultivation can contribute to the prevention of plant invasions (Dehnen-Schmutz, 2011)

Figure 6 12 **Left: *Pyrus calleryana* (callery pear). Right: *Lythrum salicaria* (purple loosestrife).**

Some cultigens planted together may cross-pollinate and form viable fruit that is dispersed into natural areas. Photo credits: Bruce Marlin, WM Commons – under license CC BY 3.0 (left) / GartenAkademie, WM Commons – under license CC BY 3.0 (right).

For example, the European Union Natura 2000 network aims to ensure the long-term survival of valuable and threatened species and habitats. Therefore, management plans are needed to prevent the deterioration of habitats and significant disturbance to species (Underwood *et al.,* 2020). The European Union invasive alien species regulations also provide legal support to prevent the introduction and spread of invasive alien species of Union concern, as Member States are obliged to undertake action to prevent and/or limit the impact of invasive alien species of Union concern (Underwood *et al.,* 2020). In Argentina, the national invasive alien species strategy requires management plans for the control of invasive alien species to be incorporated into protected area management and annual operational plans in national, provincial and municipal protected areas and private reserves (Paola & Kravetz, 2004). Protected areas in

marine and connected systems are, however, less likely to achieve successful management following establishment of an invasive alien species (**Chapter 5**, **Figure 5.1**; Simberloff, 2021; **Box 6.8**). Therefore, high-level policy instruments are needed to focus on preventative measures, for example, ballast water management systems and biofouling protocols (**Table 6.4**; **Chapter 5**, **section 5.4.4.1**).

The application of high-level indicators downscaled from global to local levels may provide a framework for protected areas to assess progress in managing biological invasions. For example, in protected areas, it is possible to monitor the number of alien taxa, the species negatively impacting biodiversity, and the trends therein (**section 6.6.3**). This indicator can be read in conjunction with indicators such as trends in species at risk of localized extinction in a protected area. Response indicators provide protected areas and conservation agencies with feedback on the extent to which essential policy and management approaches have been adopted (McGeoch *et al.,* 2010; **section 6.6.3**). Collated at a national level these responses can be used to inform global indicators such as those for measuring progress in achieving the targets of the Kunming-Montreal Global Biodiversity Framework.

Box 6 8 Marine protected areas as hotspots of invasive alien species.

Marine protected areas are created to conserve the diversity of native species and associated habitat, and protect this biodiversity from threats such as invasive alien species (Francour *et al.,* 2010). Yet, evidence is emerging that suggests marine protected areas do not provide effective, or even adequate, resistance to the introduction, establishment and spread of invasive alien species (Usher *et al.,* 1988). For example, a survey of the venomous *Pterois* spp. (lionfishes) in 71 Caribbean reefs shows that they have established in high densities on reefs with depauperate native predator assemblages, and on reefs with both a high diversity and high biomass of native predators (Hackerott *et al.,* 2013; **Figure 6.13**). A census of lionfish in the Florida Keys National Marine Sanctuary, long considered a safe refuge for biodiversity (Hickerson *et al.,* 2012), revealed a rapid increase in their spread, abundance and biomass (Ruttenberg *et al.,* 2012). On the island of Martinique, despite intensive population control efforts (e.g., public awareness, authorize and equip dive centres for Lion-fish removal; Trégarot *et al.,* 2015) inspired by the Regional Caribbean Lionfish Strategy (Gómez Lozano *et al.,* 2013), lionfish colonized the west coast of Martinique, most of it designated as marine protected areas[9]. The lionfish also colonized the isolated Parque Nacional Arrecife Alacranes and the offshore coral reefs of the Flower Garden Banks National Marine Sanctuary in the Gulf of Mexico (Johnston *et al.,* 2017; López-Gómez *et al.,* 2014).

Figure 6 13 **Lionfish are now invading the western Atlantic Ocean, from North Carolina to Brazil.**

Photo credit: Oren Klein – under license CC BY 4.0

Box 6 8

In a global hotspot (**Glossary**) of marine invasive alien species, the Mediterranean Sea, a survey of rocky reef fish assemblages in 30 marine protected areas did not find evidence for any effect of marine protected areas on invasive alien species (Guidetti *et al.,* 2014). There is evidence of up to two times higher biomass of invasive alien fish in some marine protected areas than in adjacent unprotected areas (Giakoumi *et al.,* 2012), with up to 50 per cent of fish biomass in protected areas being invasive alien species (Giakoumi, Pey, *et al.,* 2019). An assessment of the vulnerability of 142 Mediterranean Sea marine protected areas to invasive fishes and algae found that Levantine marine protected areas are dominated by invasive alien species (D'Amen & Azzurro, 2020). Effective invasive alien species policy for marine protected areas should therefore include a strong focus on prevention, along with context-specific environmental management to minimize the suitability of local habitats to invasion as currently proposed in the Action Plan Concerning Species Introduction and Invasive Species in the Mediterranean Sea (UNEP, 2014).

6.3.2 Legal and regulatory options across geopolitical scales

This section presents and discusses strengthening legal and regulatory instruments at multilateral scales **(Table 6.4)**. The goal is to present the main strategies by which agreements, laws and regulatory instruments and voluntary codes relevant at broad geopolitical scales can be strengthened. The options presented focus on the need for clear national strategies, embedded in a regional context and framed by coordinated multilateral environmental agreements.

6.3.2.1 Link national invasive alien species strategies into regional plans to align efforts and complement national strategies

The drivers facilitating invasive alien species are transboundary in nature (**Chapter 3**, **sections 3.1.1** and **3.1.3**), and their impacts are rarely restricted within political boundaries (**Chapter 4**, **sections 4.3**, **4.4**, **4.5**, **4.6**). Actions by individual countries are therefore not enough to mitigate the drivers and address the impacts of invasive alien species. Therefore, effective responses are based on shared objectives, means and approaches across legal and regulatory instruments, while also being supported by cross national collaborative actions. The need for countries to work together to identify, share information on, and coordinate around common priorities on invasive alien species could be a priority in any future or renegotiation of regional agreements. Efforts in this direction are in place in multiple trading blocs like the Southern Common Market (MERCOSUR) and the European Union **(Box 6.9)**. Ensuring this coordination may be the most effective means of reducing the risk of new invasive alien species and further spread of invasive alien species. Moreover, the gains achieved by placing national policy priorities within the context of regional and international instruments outweigh the investment required for any country deciding to go "solo". This is clearly evidenced by the existing web of policy ties across geographic scales that transcend the invasive alien species issue.

9. http://campam.gcfi.org/CaribbeanMPA/mapview.php

Box 6 9 **From Regional policy to national priorities: MERCOSUR and European Union cases.**

MERCOSUR is a regional trade agreement whose members are Argentina, Brazil, Paraguay, Uruguay and Venezuela. These countries have agreed on several regional commitments promoting action on invasive alien species: MERCOSUR Biodiversity Declaration (2006); Article 7 of the MERCOSUR Environment Framework and the Work Plan of the MERCOSUR Working Group, which acknowledges the need for managing priority invasive alien species. Also, the MERCOSUR working subgroup on the environment (SGT6) acknowledged the need to define a joint work plan on invasive alien species, including prevention, control and eradication priority actions, as part of multilateral environmental agreements and the MERCOSUR Framework Agreement on the Environment (LXIV Ordinary Meeting, 2017). The adoption of risk assessment protocols for introduction of species and MERCOSUR Resolution GMC 38/2019 on Guidelines for the Prevention, Control and Mitigation of Invasive Alien Species to reduce impacts on biodiversity, environment, health, production, economy and culture, is one of the recent regional agreements (MERCOSUR, 2019).

These agreements have not been reflected in Actions plans or in practical measures to deal with invasive alien species in different MERCOSUR countries. Two exceptions are Argentina and Brazil, both of which developed a national strategy on invasive alien species (GEF, 2016; Ministério do Meio Ambiente/ Secretaria de Biodiversidade, 2018). Uruguay recently included the promotion of the control of invasive alien species as a general goal in their National Strategy of Biodiversity (Uruguay:

Box 6 9

MVOTMA-DINAMA, 2016) and, in Paraguay, the national policies of invasive alien species are related to Wild Life Law and Resolutions 1184-85 (SEAM, 2006), which deal with control of introduction of exotic fauna and flora species.

The European Union as a party to the CBD took actions to ensure its policies comply with Article 8h of the Convention, on invasive alien species. In 2014 the European Union agreed to a legislative text related to invasive alien species, adopted by the European Parliament and the European Council: Prevention and Management of Invasive Alien Species, European Union Regulation 1143/2014 (Council of the European Communities, 2014), fulfilling Action 16 of Target 5 of the European Union 2020 Biodiversity Strategy, as well as Aichi Target 9 of the Strategic Plan for Biodiversity 2011–2020 under the CBD (Baquero *et al.,* 2021). This adoption resulted in the immediate existence of an enforceable law for all Member States (January 2015). This Regulation also emphasizes prevention, early warning systems and rapid response, while also recognizing that when prevention fails, eradication is the best management alternative, alongside long-term control measures. In summary, Regulation 1143/2014 allowed overcoming the limited coordination of national strategies on invasive alien species assisted by an information system, the European Alien Species Information Network (EASIN)[10] including an early warning system supporting early detection of invasive alien species of Union concern in Europe. It stimulates strengthening of ecosystem resilience through restoration linking with other policies, e.g., the Marine Strategy Framework Directive and the Water Framework Directive to improve the control of aquatic invasive alien species in European Union countries (Boon *et al.,* 2020; Council of the European Communities, 2008). An interesting component of the European legislation is that it includes an obligation for Member States, at Art. 13, to enforce an action plan addressing relevant pathways of introduction of invasive alien species, thus focusing on prevention rather than on reaction to new invasive alien species.

6.3.2.2 Increase coordination across multilateral environmental agreements

Over the past decade, there has been widespread adoption of multilateral environmental agreements (**section 6.1.3**). However, this pool of multilateral legal and regulatory instruments is piecemeal in the way the pathways and impacts of invasive alien species are addressed. One way to overcome this is to consider a more comprehensive international approach that focuses on sustainable development *via* the protection of biodiversity and maintaining good quality of life. The Inter-agency Liaison Group on Invasive Alien Species established by the Executive Secretary of the CBD was central to this process, but has been inactive for several years. However, at COP15, Parties invited "the Secretariat of the United Nations Economic and Social Council, the World Customs Organization [WCO], the International Plant Protection Convention [IPPC], the World Organisation for Animal Health [WOAH], the World Health Organization [WHO], the Food and Agriculture Organization of the United Nations [FAO] and its Codex Alimentarius, the Secretariat of the Convention on International Trade in Endangered Species of Wild Fauna and Flora [CITES] and the Invasive Species Specialist Group [ISSG] of the International Union for Conservation of Nature [IUCN], within the scope of their respective mandates, to support the national implementation of the Kunming-Montreal Global Biodiversity Framework with regard to targets and actions related to invasive alien species, including their monitoring and reporting"(CBD, 2022c).

While discussions leading to an increase in coordination across multilateral instruments is more likely to take place for global scale instruments due to their global scale implications, coordination of regional multilateral instruments faces many difficulties and obstacles, particularly in developing countries. Linguistic, cultural and political differences within regions also pose major obstacles for coordination. As discussed by Burgiel (2015), the Caribbean region is an example of the difficulties of integrating regional policy instruments due to multitude of languages and historical affiliations, the status of overseas territories and political issues. That said, the efforts of regional intergovernmental or nongovernmental entities provide a primer for building synergies and increasing coordination across legal and regulatory instruments (Burgiel, 2015).

6.3.2.3 Embed in multilateral agreements mechanisms to enhance coordination and information exchange between policy instruments

The inherent complexity in managing biological invasions could be countered by communication and information exchange among a wide range of stakeholders including across national borders and across government agencies, the private sector, the scientific and research community and the general public. A system for communication and information exchange would be supported by a well-functioning infrastructure. Effective decision-making for alien species is only possible with timely access to scientific and technical information. Embedding the need of institutions that facilitate/mandate information generation and exchange into multilateral agreements can provide a mechanism

10. https://easin.jrc.ec.europa.eu/easin/

to achieve the goals of existing agreements and provide information for the application of guidance documents. At a minimum, identification and monitoring of alien species would be part of the mandate of the proposed knowledge-generating institutions. Most of the international legal instruments, agreements and texts relevant to invasive alien species highlight the importance of risk analysis principles, notification procedures and information exchange. Examples of information exchange infrastructures include the CBD Access and Benefit-sharing Clearing-House and the FAO Forest invasive species home. However, information is usually sectorized in instrument focused clearing houses. There is also a problem with limited exchange of information across government agencies, and from the scientific and research community to policymakers and the public (**section 6.6**).

The need for an organizing (multi)national authority is clear due to the fragmented nature of existing policy instruments, which limits the capacity of a coordinated and unified response to the invasive alien species problem (Shine *et al.,* 2000; Stoett, 2007). The benefits of creating such an organizing (multi)national authority are the capacity to:

- Coordinate policy across national agencies and countries within a trading block;
- Unify risk analysis of invasive alien species introduction pathways, and how these risk analyses are implemented by relevant authorities;
- Develop effective early detection and rapid-response activities;
- Promote the exchange of information among all the stakeholders and Indigenous Peoples and local communities involved in the prevention, control and eradication of invasive alien species;
- Enhance the capacity to be cost effective in preventing and mitigating strategies given the interdependence of management;
- Enhance the capacity to synthesize and integrate information from international agreements, regional/national agencies, sectorial initiatives and university research.

An example of such a multilateral coordinating body is the Committee for Environmental Protection (CEP) which has, for example, developed a Non-Native Species Manual for activities of the nations active in the Antarctic **(Box 6.10)**.

Box 6 10 The Committee for Environmental Protection as a coordinating body for Antarctic alien species problems.

Policy context: Policies that are relevant to biodiversity and to ecosystem services in the Antarctic region are developed, usually independently, by the Antarctic Treaty Consultative Parties (ATCPs), the Commission for the Conservation of Antarctic Living Resources (CCAMLR) and by the States responsible for the islands in the Southern Ocean (north of 60°S). The ATCPs are advised by the Committee for Environmental Protection (CEP), established by the Protocol on Environmental Protection to the Antarctic Treaty of 1991 and by the Scientific Committee on Antarctic Research (SCAR), a committee of the International Science Council (Protocol Article 10.2; **Supplementary material 6.1**).

Invasive alien species: Based on the advice of the CEP, the ATCPs have placed significant focus on preventing invasive alien species introductions to and impacts on the area south of 60°S. Current guidance for doing so is encapsulated in the Non-Native Species Manual of the CEP (ATCM, 2019), hereafter the Manual). The Manual covers the unintended introduction of species to the Antarctic region and the movement of species within Antarctica, and is an example of the effective translation of recent research to policy through the CEP (e.g., Hughes & Convey, 2010, 2012; Lee & Chown, 2011). Although the pace of such translation and uptake has been criticized and there is a lack of evidence to quantify the implementation of different biosecurity measures across more than a handful of national programmes, the rate of development of responses within the Antarctic Treaty System (ATS) has been relatively rapid, with these responses exceeding those typically expected elsewhere, as measured through a comparison with international responses to the relevant Aichi Targets of the Strategic Plan for Biodiversity 2011-2020 (Chown *et al.,* 2017).

Practical guidelines: The Manual has also been supplemented by other practical guidance for those operating in the region. Perhaps the best example is the COMNAP/SCAR Invasive alien Species Voluntary Checklists for Supply Chain Managers (SCAR & COMNAP, 2019), which provides practical guidance (and the evidence underlying it) to prevent the introduction of non-indigenous species to Antarctica. Other organizations, such as the Antarctic tourism industry body, the International Association of Antarctica Tour Operators (IAATO), have similar guidance for its members (IAATO, 2020). In the 2019/2020 season, more than 74,000 tourists visited the Antarctic and numbers are expected to rise.

Although the Manual makes reference to marine invasions, including the Practical Guidelines on Ballast Water Exchange in the Antarctic Treaty Area (ATCM, 2006), it also identifies the need for further guidelines for preventing and responding to marine invasive alien species (McCarthy *et al.,* 2019). The

Box 6 10

Manual contains a great deal of advice for terrestrial systems, including flow charts on how to respond to introductions. Notwithstanding all of the advice and agreements, Antarctic Treaty policy implementation proceeds through implementation in national law, which is highly variable between the nations that are party to the Antarctic Treaty and Protocol (Hughes & Pertierra, 2016). These include all nations that are active in Antarctica.

Progress and prospects: What should be done to limit the impacts of invasive alien species and the reasons for doing so, are uniformly articulated to the ATCPs *via* the Manual (ATCM), 2019). As a result, considerable progress has therefore been made in addressing the requirements for reducing the introduction and spread of invasive alien species, in monitoring the situation, and in responding to new incursions and developing eradication approaches (Hughes & Convey, 2012; McGeoch *et al.,* 2015).

The broader Antarctic region is changing rapidly as a consequence of global climate change (Le Roux & McGeoch, 2008; Lebouvier *et al.,* 2011; Rintoul *et al.,* 2018; Swart *et al.,* 2018), with most analyses indicating that risks of establishment, spread and impact of alien species will increase (Frenot *et al.,* 2005; Aronson *et al.,* 2015; Duffy *et al.,* 2017; McClelland *et al.,* 2018; McCarthy *et al.,* 2019; Pertierra *et al.,* 2020). Human activity in the region is also growing due to growth in scientific stations and numbers of science and support personnel, and in numbers of tourists (Chown & Brooks, 2019). Thus, invasive alien species policy requirements for the future will have to focus especially on what these changes mean for introductions from elsewhere into the Antarctic region. In the face of these challenges, a focus on better and coordinated biosecurity measures, for prevention, and the development of clear surveillance policy and practices to identify and characterize new establishments as they occur is essential, especially for marine systems (Aronson *et al.,* 2015; Hughes *et al.,* 2015; Hughes & Pertierra, 2016).

6.3.3 Legal and regulatory options at national scales

National investment in invasive alien species prevention and control generally requires governments to take the lead, especially if outcomes are intended to fulfil the public interest (Early *et al.,* 2016). As discussed above, a coordinated approach can indeed be challenging for several reasons, including administrative fragmentation and the need to take into account free trade agreements. To take the lead, each level of government needs the legal mandate to develop its relevant invasive alien species strategy (e.g., Genovesi & Shine, 2004) and collectively agreed implementation plan (e.g., National Invasive Species Council, 2008). In addition to these plans, countries could adopt legal and regulatory options to address invasive alien species, such as regulation of import; regulation of possession, trade, transport and reproduction in captivity; regulation of introduction into the wild; mandatory management of pathways of introduction; or mandatory eradication or control actions.

As with all significant government-led investments, legislative authority is necessary to engage budgetary expenditure (V. M. Adams *et al.,* 2018). Quarantine, biosecurity, environmental protection or marine protection acts of government can form the legislative basis for spending (Genovesi *et al.,* 2015; Pyšek *et al.,* 2020). Once legislative authority is in place then national invasive alien species strategies and management plans can be developed and implemented through collective decision-making and a co-investment process following (as far as possible) best practices (e.g., Victorian Government, 2010). National scale benefits from management of biological invasions cannot happen without this legislative authority empowering a government led response.

6.3.3.1 National invasive alien species strategies that identify the full suite of policy and management needs and priorities

Except for some provisions under the Sanitary and Phytosanitary Agreement, most governments have done relatively little to establish policies and programmes intended to limit the movement of invasive alien species (**section 6.1.3**; Early *et al.,* 2016; Pagad *et al.,* 2020; Turbelin *et al.,* 2017). Specifically, relatively few countries have invested in a comprehensive "biosecurity" approach or coordinated policies and programmes across relevant sectors for the management of biological invasions (**section 6.3.1**). One of the most effective and comprehensive approaches that governments can implement to minimize the spread and impact of invasive alien species is the development of national strategies and associated action plans, such as National Invasive Species Strategies and Action Plans (NISSAPs). Strategies for preventing and controlling invasive alien species can also be incorporated into NBSAPs to ensure policy connections and coherence. NBSAPs could also be used to enhance the coordination between other sectors, as suggested in **section 6.3.1.1**, *via* a national office as has been the case for the Great Britain Invasive Non-Native Species Strategy **(Box 6.11)**.

Following the recommendations and considerations included in multiple CBD decisions, strategy and action plans could:

- Define clear and measurable national targets (CBD decision X/2 paragraphs 3(b) and (c)).
- Mainstream biodiversity, communication, monitoring and reporting (CBD decisions X/2 paragraphs 3(d) and (f); XI/8 paragraph 4) into broader environmental, economic and social national and local plans (CBD decisions X/2 paragraph 3(d), X/33 paragraph 8(k)).
- Define funding needs (CBD decisions X/31 paragraph 11 and XI/ paragraph 17).
- Have a clear mechanism for providing financial resources (CBD decisions X/26 paragraph 3 and XI/ paragraph 17, 25) and ensuring resource mobilization (CBD decision X/3 paragraph 2).
- Promote cooperation with other multilateral environmental agreements (CBD decisions X/5 paragraph 3 and XI/6 paragraphs 10 and 11), particularly those focused on addressing climate change (X/33 paragraph 8(k) and XI/19 paragraph 7(a)).
- Have specific considerations for protected areas (CBD decisions X/31 paragraphs 1(c), 11, 26 and XI/2 paragraph 1(a)).
- Have specific considerations for different ecosystems such as marine/coastal (CBD decision X/29 paragraphs 7, 18, 67), islands (CBD decision X/15 paragraph 4(b)), mountains (CBD decision X/30 paragraphs 4, 8) and dry and sub-humid lands (CBD decision X/35 paragraph 2(g)).
- Broadly consider the value of nature by engaging multiple sectors (CBD decisions X/32 paragraph 2(g) and X/44 paragraph 6).
- Provide positive incentives (direct or indirect) that encourage achievement of biodiversity-friendly outcomes or support activities that promote the conservation and sustainable use of biodiversity (CBD decisions X/44 paragraph 6 and XI/30 paragraphs 3, 6, 7, 9).
- Consider gender dimensions (CBD decisions X/19 paragraph 5 and XI/9 paragraph 7), Children and youth (CBD decision XI/8 B paragraph 1).
- Involve civil society (CBD decisions XI/8 C paragraph 1) and Indigenous and local communities (CBD decisions XI/14 B paragraph 17).

Box 6 11 Coordinating action against invasive alien species in Great Britain: Great Britain Invasive Species Strategy and integration with plant and animal health.

The Great Britain Invasive Non-native Species Strategy (Secretariat, Great Britain Non-native Species, 2015) is an example of a National Invasive Alien Species Action Plan. It sets the strategic vision and national objectives for invasive alien species management in Britain and identifies 59 key actions to achieve their delivery. It is a partnership document developed by a combination of government bodies, environmental non-governmental organizations and organizations representing trade and industry.

The implementation of the Great Britain Strategy is overseen by a Programme Board comprising eleven government departments and delivery bodies. This reflects the wide range of threats posed by invasive alien species. The work of this Board is facilitated by a small secretariat (3.6 staff), which acts as a point of contact for stakeholders, establishes working groups on behalf of the Board to deliver specific actions, coordinates communications activity and runs a risk analysis mechanism.

The strategy has been broadly successful and has led, among other things, to the development of an invasive alien species risk analysis mechanism to support the ban on sale of invasive alien species; action plans to tackle key pathways of introduction; two awareness raising campaigns to reduce spread of aquatic organisms and ornamental plants; contingency plans and rapid responses; and a network of local action groups established to help tackle more widespread species (**Glossary**) in their local area. Examples of success include the eradication of five species from Britain (*Vespa mandarinia* (northern giant hornet), *Xenopus laevis* (African clawed frog), *Pimephales promelas* (fathead minnow), *Ameiurus melas* (black bullhead), *Lithobates catesbeianus* (American bullfrog)) and the ongoing eradication campaigns for three others (*Ludwigia grandiflora* (water primrose), *Myiopsitta monachus* (monk parakeet) and *Pseudorasbora parva* (topmouth gudgeon)). Britain has pioneered one of the largest invasive alien bird eradications in the world. In order to protect the indigenous *Oxyura leucocephala* (white-headed duck), the alien *Oxyura jamaicensis* (ruddy duck) has been reduced from a peak of over 6,000 individuals in 2001 to a handful of individuals in 2015 (Handerson, 2009; Secretariat, Great Britain Non-native Species, 2015).

However, despite these notable successes, overall indicators show the strategy is having little impact on the total numbers of invasive alien species establishing and spreading in Britain. There are about 2,000 alien species established in the United Kingdom, 10-15 per cent of which are invasive. Despite the Great Britain Strategy this number is increasing by

Box 6 11

approximately 10-12 new species per annum. An independent parliamentary enquiry (UK Parliament, 2019) attributed this increase to the dearth of resources available to tackle invasive alien species, including the lack of an inspectorate to prevent and intercept incursions. Only 0.4 per cent of Great Britain's total biosecurity budget is spent on invasive alien species despite their being similar, in terms of numbers of harmful organisms, to animal and plant health regimes. Unsurprisingly, other biosecurity regimes with much greater funds and dedicated inspectorates have been largely successful in their objectives by comparison. Indeed, animal and plant health regimes in Britain have prevented the introduction of 98 per cent of listed species in the past 20 years. By comparison, with no invasive alien species inspectorate, attempts to stem the flow of invasive alien species into Britain have been largely unsuccessful, with approximately 25 new invasive alien species establishing in the last 20 years.

Since 2013 the Department for Environment, Food and Rural Affairs in the United Kingdom has been working to develop a more integrated approach to biosecurity, incorporating animal health, plant health and invasive alien species. This has included establishing monthly meetings to review new and developing biosecurity threats across these regimes. Meetings are chaired by the Minister for Biosecurity, Marine and Rural Affairs, and attended by the Chief Vet, Chief Plant Health Officer and Chief Non-native (Alien) Species Officer. To support these meetings, emerging threats from invasive alien species, pests and diseases are reviewed within the same risk matrix. The matrix uses information from existing risk assessments to place organisms according to likelihood of an outbreak and potential impact. Impact is assessed using standardized criteria for economic, environmental and human health, which are then monetized to produce a single metric. This approach provides a straightforward overview of changing biosecurity threats and allows the minister and officials to compare and prioritize threats for action. It has resulted in greater integration across biosecurity regimes and the opportunity to utilize the greater experience of plant and animal health teams to support response to invasive alien species.

Strong and implementable NBSAPs, aligned with international regulatory frameworks, can help to spur the strategic actions and establish the properties required for the successful prevention and control of biological invasions, in alignment with the Kunming-Montreal Global Biodiversity Framework (CBD, 2022a) invasive alien species target (Target 6). Furthermore, coordinated efforts to strengthen national regulatory instruments can help address for online trading (aligned with Target 5), the creation of appropriate policies for the development and use of responsible environmentally sound technologies (aligned with Target 17), as well as making available data and information accessible (aligned with Target 21).

It is important to highlight that national action plans should implement existing international standards as a minimum standard but could also take full advantage of the rights under international agreements that allow for stricter protection measures. Also, a key instrument of national action plans is the possibility of creating departments or agencies specifically dedicated to the governance and implementation of invasive alien species legislation. By taking these steps, national strategies can define instruments and processes to ensure the need for shared efforts and commitments, and the understanding of the specific roles across sectors and Indigenous Peoples and local communities and multi-scale coordination of response programmes.

6.3.3.2 Careful delineation of legal authorities that would enable the implementation of risk assessment and surveillance protocols

The nature of the risks of invasive alien species depends on the stage of the biological invasion (Epanchin-Niell, 2017; Springborn *et al.,* 2011). In the introduction stage, preventing or minimizing alien species arrivals is achieved through actions that address both intentional and unintentional introductions. Prevention is also best achieved when clearly defining "who" has the authority for the detection of potential invasive alien species and understanding which responsible bodies of the legal and regulatory framework, such as Phytosanitary (defined under the IPPC) and animal health (defined under WOAH) mandates, allow actions. Actions designed to prevent establishment of potential invasive alien species are termed "early detection and rapid response" (EDRR), with the desired response eradication of the incipient invasive alien species (Meyerson & Simberloff, 2020).

Policies aimed at preventing or minimizing the possible effects of intentional introductions need to consider who is the responsible body for providing transport and introduction permits. The actions of these offices should focus on providing permits for proposed planned introductions and should be based on information coming from risk assessment procedures such as the Australian Weed Risk Assessment (Pheloung *et al.,* 1999), the Plant Protection and Quarantine weed risk assessment (PPQ WRA; Koop *et al.,* 2012) and the Non-native Species

Secretariat (NNSS) Risk Assessment Scheme for Great Britain (NAPRA Network, 2010). In the context of transport and introduction, a policy of inspection and/or treatment at the port of departure can duplicate the effect of other policy of inspection and/or treatment at a port of entry. However, if a departure and arrival policy is established, policy integration would require an international agreement. A key part of such agreement is aligning the authorities with the mandate of inspection and/or treatment.

6.3.3.3 Embed both surveillance and monitoring into policy instruments focused on invasion management

Invasive alien species can cross borders and, therefore, preventing their introduction can only be achieved with pre-border, border and post-border surveillance systems (Anderson *et al.,* 2017; Poland & Rassati, 2019). Successfully controlling invasive alien species or preventing biological reinvasions relies on long-term monitoring for early detection and rapid response (Amorim *et al.,* 2014; European Environment Agency, 2010b; Franklin *et al.,* 2011; Oswalt *et al.,* 2021; Roy & Roy, 2008). These activities are essential to minimizing their impacts, developing economically efficient and ecologically relevant management programmes and promoting citizen engagement and educational outreach (McGeoch & Squires, 2015; Oswalt *et al.,* 2021). Furthermore, these activities are at the core of CBD Guiding Principle 5: Research and monitoring (CBD, 2002) and are considered a fundamental tool to address the problem of invasive alien species. Continuous monitoring systems that use essential biodiversity variables (EBVs; **Glossary**; **section 6.6**) can also help evaluate the effectiveness of policy and management strategies and fill a fundamental knowledge gap in environmental policy.

For example, the European Union Regulation 1143/2014 on invasive alien species (Council of the European Communities, 2014) has specific provisions for member states regarding the implementation of surveillance systems to detect the presence of alien species of Union concern as early as possible and take rapid eradication measures to prevent their establishment. However, as noted by Latombe *et al.* (2017), in 2010, only 26 per cent of countries reported the establishment of national surveillance systems and monitoring activity. Additionally, the capacity to detect and react promptly to new invasions or re-invasions is often limited (see, for example, Genovesi, 2005) and is usually not comparable across countries (Latombe *et al.,* 2017). Furthermore, when monitoring takes place, it occurs at multiple unconnected scales – from national programmes to local citizen science (**Glossary**) initiatives (McGeoch & Squires, 2015; Oswalt *et al.,* 2021), which further complicates their interoperability. As a result, which agency oversees surveillance and monitoring activities, and where/when/how such activities occur, varies widely between countries.

Technical scientific bodies must be tasked with continuous monitoring activities, diagnosis, risk assessment, storage and circulation of information, reporting, identification and enforcement of appropriate responses. At a higher level, a global monitoring system is a critical tool to be included in multilateral environmental agreements to manage biological invasions effectively. This goal is within reach, as pointed out by Latombe *et al.* (2017).

6.3.3.4 Develop policy and regulatory instruments to underpin innovative management programmes

New technologies can be developed or translated from other contexts to improve any aspect of innovative management programmes for biological invasions (van Rees *et al.,* 2022). Innovation is the translation of invention through proof-of-concept to readiness to be deployed, leading to desirable outcomes (Baregheh *et al.,* 2009). Frameworks can drive innovation in management of biological invasions, particularly in the context of public good outcomes (van Rees *et al.,* 2022). Indeed, government support is also needed to find better solutions to management challenges from idea and blueprint to a full technology readiness level. Not all the technologies needed are available, nor is it clear what future valuable technologies might be. Only through policy development will governments invest in technology development and deployment (Burke *et al.,* 2005).

Innovation can be achieved with cultural change through community acceptance of the value of the technology interacting with institutional change, aligning to regulate technology deployment (Stilgoe *et al.,* 2020). Achieving cultural acceptance of technology is not guaranteed and often hinges on obtaining social license and acceptability and demonstrating that the benefits of the technology outweigh any risks, including ethical considerations. Cultural acceptance is never a fixed position (Crowley *et al.,* 2017b). Institutional change includes the necessary policy or regulatory environment that will regulate use (Burke *et al.,* 2005). An example was the invention and adoption of chemical pesticides for pests, weeds and diseases from the 1940's. Starting with dichlorodiphenyltrichloroethane (DDT), the consequences of its initial use led to completely national risk-based legislation and regulation on how when and where it could be used. This eventually resulted in DDT being banned as evidence of negative impacts became available (Mansouri *et al.,* 2017). This nonetheless opened the door for development and application of future generations of less toxic chemicals to which the initial regulations needed to be adapted (Handford *et al.,* 2015). Even the most benign chemical pesticides have now

increasingly lost public favours based on long-term evidence mediated through changing cultural acceptance (Kudsk & Mathiassen, 2020). The same processes are necessary in the adoption of any new technology however beneficial, so it is the role of government to manage and respond to this culturally driven policy and regulatory process, without which any benefits from new technologies towards management of biological invasions will not be obtained.

6.4 ENGAGEMENT AND COLLABORATION WITH STAKEHOLDERS AND INDIGENOUS PEOPLES AND LOCAL COMMUNITIES

The engagement of stakeholders (**Chapter 1**, **section 1.5.1** for the definitions of stakeholder groups) and Indigenous Peoples and local communities can help construct coherent policy and management plans that are appropriate to local environmental and cultural realities (e.g., Adriaens *et al.,* 2015; Bravo-Vargas *et al.,* 2019; Bryce *et al.,* 2011; Dehnen-Schmutz *et al.,* 2010; Fischer *et al.,* 2014; Gaertner *et al.,* 2017; García-Llorente *et al.,* 2008; S. Liu *et al.,* 2010; Marchante *et al.,* 2017; Novoa *et al.,* 2016; M. S. Reed, 2008; M. S. Reed *et al.,* 2009; M. S. Reed & Curzon, 2015; Shackleton, Adriaens, *et al.,* 2019; Stokes *et al.,* 2006; Touza *et al.,* 2014). As outlined earlier (**Chapter 5**, **section 5.6.2.1**), there are many examples where effective regulatory, social responsibility and incentive-based systems have and continue to support effective industry and landowner engagement in the prevention and control of invasive alien species. This section outlines the context and summarizes the purposes of engaging stakeholders and Indigenous Peoples and local communities (**section 6.4.1**). It assesses the general enabling factors for successful engagement (**section 6.4.2**), as well as factors contributing to successful collaboration with Indigenous Peoples and local communities on biological invasions more specifically (**section 6.4.3**). Finally, the section explores the different governance network options for collaborative action (**section 6.4.4**).

6.4.1 Reasons for inclusive engagement

New approaches to governance for biological invasions reflect broader shifts in environmental governance (Chaffin *et al.,* 2014), emphasizing the interconnectivity of ecological and social systems and the uncertainty associated with complexity and rapid environmental change (**section 6.7**). These approaches recognize the need for more integrated multi-level or "polycentric" governance (Anderies *et al.,* 2013; Bodin, 2017; Lubell, 2013; Ostrom, 2010) and democratic legitimacy (Stoett *et al.,* 2019), as well as the imperative to achieve societal consensus, engagement and fairness (CBD, 2020a). The general shift is toward greater consideration of the adaptive-collaborative governance model (**section 6.2.4.1**), where a collective decision-making process is one "that allows diverse sets of actors who share an interest or stake in a policy or management issue to work together toward mutually beneficial outcomes" (Lynch, 2020).

As an early example, **Box 6.12** describes how New Zealand's biosecurity legislation underpins new collaborative forms of governance of invasion pathways in marine areas.

There has been no comprehensive review of the on-the-ground experiences of stakeholders and Indigenous Peoples and local communities or their engagement in management and governance of biological invasions (but see Shackleton *et al.,* 2019 for a review of stakeholder involvement in invasive alien species research). The following reasons for engagement are taken from a limited selection of the literature based on experiences with governance and management of biological invasions:

Knowledge-related

Engaging with stakeholders and Indigenous Peoples and local communities facilitates knowledge and information sharing, creating information flows across scales (Lansink *et al.,* 2018). This contributes to the development of sufficient shared awareness of biological invasions, including understandings of drivers, processes, impacts and possible responses (Carter *et al.,* 2021). Bridging different knowledge systems associated with different disciplines and perspectives (Barney *et al.,* 2019) provides greater legitimacy of knowledge underpinning actions and leads to higher quality and more context-relevant decisions (J. M. Evans *et al.,* 2008; M. S. Reed & Curzon, 2015). This also permits social learning for adaptive management that can assess and reduce uncertainty, build adaptive capacity (S. Liu & Cook, 2016; Maclean *et al.,* 2018; Novoa *et al.,* 2016; Söderström *et al.,* 2016), make monitoring more cost effective (Novoa *et al.,* 2016) and facilitate collaborative research (Shackleton, Adriaens, *et al.,* 2019).

Risk assessment

Engaging with stakeholders and Indigenous Peoples and local communities facilitates decision-making about risk prioritization by addressing people's concerns so that: (1) associated uncertainty can be discussed (S. Liu *et al.,* 2011), (2) diverse values and perceptions can be brought into the risk assessment/decision process to negotiate consensus, (3) risk can be contextualized in broader contexts, (4) measures targeted to the local context can be formulated, (4) decision-making becomes transparent and

Box 6 12 New Zealand's shift towards adaptive collaborative governance for biological invasions.

In part due to the recognition that reactive species-specific management designed for terrestrial invasions is not suited to the marine environment, New Zealand made a major shift towards adaptive collaborative governance. Legislatively enacted in a 2012 amendment to the Biosecurity Act 1993, governance for biological invasions was moved away from species-specific management to a proactive focus on vectors (**Glossary**) and invasion pathways that could better serve to prevent establishment rather than undertake costly remedial action. The first Marine Regional Pathway Management Plan, developed in Fiordland, a World Heritage Site of the United Nations Educational, Scientific and Cultural Organization (UNESCO; **Figure 6.14**), was "driven by a community-based, multi-stakeholder and Indigenous Peoples and local communities and government agency partnership" initiated by the Fiordland Marine Guardians, a stakeholder and Indigenous Peoples and local communities group composed of "representatives of Ōraka Aparima Rūnaka Inc of Ngāi Tahu iwi, commercial fishers, recreational fishers and charter boat operators". The "Guardians" are responsible for the integrated management of the Fiordland Marine Area and were officially empowered by national legislation to advise and recommend government and management agencies on all aspects of management, facilitate and promote integrated management, prepare and disseminate information and monitor and advise on threats, among others (Cunningham *et al.,* 2019).

Figure 6 14 **Fiordland National Park.**

The Marine Regional Pathway Management Plan developed in Fiordland is an example of adaptive-collaborative governance. Photo credit: Bernard Spragg. NZ from Christchurch, New Zealand – Milford Sound New Zealand., WM Commons – Public domain.

(5) complex trade-offs between different options can be assessed (Carter *et al.,* 2021; S. Liu & Cook, 2016; Moon *et al.,* 2015). For example, the Mohawks of Kahnawá:ke (Quebec, Canada) oppose spraying chemicals on the land as they feel it would contradict their spiritual connection with nature (IPBES, 2022). There can also be concerns over animal welfare and rights when considering possible management and eradication interventions **(Box 6.13)**. A particular trade-off to consider is the need for rapid response to maximize the likelihood of eradication early in the invasion curve (**Glossary**), *versus* the time and cost of broad stakeholder inclusion in decision-making. This trade-off can however be managed by ensuring as far as possible that collaborative and inclusive decision-making structures are in place before new invasive alien species arrive.

Consensus building

By increasing their involvement, developing shared aims, overcoming barriers to coordination and collaboration, and building trust (Carter *et al.,* 2021; Graham, 2019; Lynch, 2020), engagement with stakeholders and Indigenous Peoples and local communities can reduce and help manage conflict (Moon *et al.,* 2015; Shackleton, Adriaens, *et al.,* 2019), including around "conflict species" (Woodford *et al.,* 2016; **Chapter 5**, **section 5.6.1.2**). It

increases public support, acceptance, ownership and buy-in (Lansink *et al.,* 2018), which minimizes the risk of unintended consequences and avoids the costs of failed measures (S. Liu & Cook, 2016; M. S. Reed & Curzon, 2015). Engagement can help to better manage the unequal distribution of costs and benefits (Novoa *et al.,* 2016) by appropriately sharing and differentiating responsibilities for management and increasing enforcement capacity (S. Liu & Cook, 2016; **section 6.7**).

Economic effectiveness and efficiency

Engaging with stakeholders and Indigenous Peoples and local communities ensures that interventions are efficient, equitable, and provide the correct incentives (e.g., that are not perverse for some or over-reward other stakeholders). This also increases the participation of economic stakeholders such as land owners, small businesses and corporations, and can help avoid the "tragedy of the commons" (**Glossary**; McAllister *et al.,* 2015).

Decision-making under uncertainty and complexity

Engaging with stakeholders and Indigenous Peoples and local communities enables adequate characterization and management of complex problems. It can also help to find solutions when conflicting perspectives, objectives and management goals make invasion problems difficult to characterize or resolve (J. M. Evans *et al.,* 2008; Woodford *et al.,* 2016). It allows a balancing of social, economic and ecological sustainability objectives and values across multiple interrelated interests (Carter *et al.,* 2021), leading to better decision-making under a diversity of local contexts. Action can then be adapted to local ecological, social and political contexts (McAllister *et al.,* 2015).

Coordination

Engaging with stakeholders and Indigenous Peoples and local communities facilitates coordination in complex situations between many apparently independent groups that have a wide range of interests, motivations and resources and who are directly or indirectly engaged in some aspect of invasions at multiple spatial scales (Barney *et al.,* 2019; Dandy *et al.,* 2017). It may help to create "institutional fit" within scales, bridge scales and develop cross-scale interactions to match the multiple scales of the problem (McAllister *et al.,* 2015). It can also help to meet multiple goals of different stakeholders with different needs for nature's contributions to people arising from the same ecosystem (Failing *et al.,* 2013; D. M. Martin *et al.,* 2018; Nel *et al.,* 2016). Responses to biological invasions may indeed need or benefit from the combination of public and private assets and joint actions by public and private sectors. Better coordination avoids competition and free-riders and contributes to reducing overall costs (Failing *et al.,* 2013; D. M. Martin *et al.,* 2018; Nel *et al.,* 2016), or shifting costs of management or impacts from one community, stakeholder to another.

Respect for rights, fairness

Engaging with stakeholders and Indigenous Peoples and local communities promotes democratic governance, where stakeholders have a direct voice in decisions that affect their environments and lives. It also encourages public engagement in publicly-funded efforts, influences decisions that affect people's good quality of life, and ensures accountability and fairness (Carter *et al.,* 2021; J. M. Evans *et al.,* 2008; S. Liu & Cook, 2016; M. S. Reed & Curzon, 2015). Finally, it ensures compliance with governance directives and stakeholder and Indigenous Peoples and local communities demands and rights for engagement (IPBES, 2022).

Box 6 13 Invasive alien species control and animal rights.

When invasive alien species are prioritized for control, ecological and economic aspects often take precedence, whereas species welfare can be underappreciated. In cases where the invasive species is associated with human values, and the control mechanism is lethal, unaddressed ethical issues in management actions can create conflict between stakeholders and Indigenous Peoples and local communities, including animal welfare groups and invasive alien species managers (**Figure 6.15**; **Chapter 5**, **Box 5.13**). Such conflict has been observed during lethal control of invasive *Erinaceus europaeus* (European hedgehog) on the Scottish island of South Uist (Warwick, 2012), of *Equus caballus* (horse) in parts of Northern America (Bhattacharyya & Larson, 2014), of *Trichosurus vulpecula* (brushtail possum) in New Zealand (Beausoleil *et al.,* 2016), and of the introduced *Epiphyas postvittana* (light brown apple moth) in parts of the United States of America (Zalom *et al.,* 2013). Such conflict delays invasive alien species control programmes, thereby potentially escalating the impact on native biodiversity, a point which is often not acknowledged by the parties in conflict (Russell *et al.,* 2016).

Consensus amongst invasive alien species managers, stakeholders and Indigenous Peoples and local communities, including animal welfare groups, has often been achieved through informed conversations. For example, in parts of the United States managers involved animal welfare groups early in the process of management to gain support for lethal control of invasive alien *Sus scrofa* (feral pig; Perry & Perry, 2008). Furthermore, involving local people while planning invasive alien species control measures can not only spread awareness

Box 6 13

about the severe impacts of such species, but also result in socially acceptable mechanisms for controlling invasive alien species. For example, government and indigenous community co-management of Kakadu National Park in Australia resulted in acceptable control of invasive feral pigs (Robinson *et al.,* 2005). These examples suggest that management of biological invasions can be achieved with horizontal integration of different sectors and vertical integration of different governance scales (**section 6.3**). Latent development of public awareness on invasive alien species control and use of popular media to communicate evidence (or curb misinformation) during a conflict-like scenario remains central to inclusive and successful invasive alien species management programmes (Crowley *et al.,* 2017a).

Figure 6 15 **Public display to support animal rights.**

Public display of a message by People for the Ethical Treatment of Animals (PETA) in Australia about responsible ownership of pet cats to stop them turning feral and getting killed in a lethal control programme. Photo credit: PETA Australia – under license CC BY 4.0.

6.4.2 Options for improving engagement with invasive alien species-related activities

6.4.2.1 How Indigenous Peoples and local communities participation can be better integrated with national policies and global efforts

Collaboration between Indigenous Peoples and local communities and other stakeholders is an underlying theme in calls for their participation in invasive alien species management efforts (S. M. Alexander *et al.,* 2017; Peltzer *et al.,* 2019; Reo *et al.,* 2017). This collaboration could take the form of "a strong and sustainable institution that can raise awareness, mobilize communities and design appropriate management plans" (**section 6.7**; Tilahun *et al.,* 2017), including:

- Use of community-led institutions that can bring together community members and make rapid decisions to respond to change, manage or pool communal resources, build leadership, facilitate interaction and demonstrate practices (Guneratne, 2002);
- Collaboration between Indigenous Peoples and local communities, researchers and government officials to prevent, detect and respond to invasive alien species, and
- Efforts to ensure the conservation of habitats on indigenous lands and leadership in biodiversity conservation and facilitate voluntary partnerships (Schuster *et al.,* 2019). For example, an agreement was signed between Sami people and the Norwegian government, grounded in the International Labour Organization Convention on Indigenous and Tribal Peoples in independent countries. This provides Sami

people with the right to be consulted on all matters of importance for the Sami (Broderstad & Eythórsson, 2014), using integrated approaches in which potential methods of control are implemented on a case-by-case basis (Broderstad & Eythórsson, 2014).

6.4.2.2 Factors contributing to failure and success of engagement with stakeholders and Indigenous Peoples and local communities

There are now many documented examples of stakeholders and Indigenous Peoples and local communities engagement processes that have failed to deliver intended outcomes for the environment, or even led to negative unintended consequences (Coglianese, 1997; Cooke & Kothari, 2001; Gerrits & Edelenbos, 2004; Lane & Corbett, 2005; Staddon *et al.,* 2015), for example, by inflaming latent conflicts (Emery *et al.,* 2015; Redpath *et al.,* 2013). As a result, criticisms of engagement practice have ranged from tokenism, where participants are manipulated to legitimize decisions, to broader critiques that key groups may not have the information, skills or equality needed to participate in effective governance, knowledge sharing, or learning processes (**section 6.4.4**).

There is no reliable "one-size-fits-all" blueprint for collaborative governance (**section 6.2.3.1**), but in response to these criticisms, Reed *et al.* (2018) distinguished different levels of engagement, and factors that might in theory explain why engagement does or does not deliver intended outcomes. Levels of engagement can be adapted to the purpose and context of the process, rather than necessarily aiming for the highest levels of engagement, such as co-production **(Figure 6.16)**. A conceptual model of participation that is inclusive and empowering can be used to build stronger participation and engagement (Bell & Reed, 2022):

- Before: Consider the role of factors that precede an effective participatory process (e.g., the creation of safe spaces and overcoming barriers to engagement to ensure the process is inclusive, including women and other marginalized groups).
- During: Take into account the factors that affect empowerment during the engagement process (e.g., equality between participants that respects and values different knowledge systems – including local knowledge and experience of invasive alien species) and agency, including freedom (from fear) and access to the resources and other means necessary to actively participate.
- After: Foresee factors that may continue to build empowerment or disempower participants after the process has concluded (e.g., accountability, ensuring decisions are implemented and reflect outcomes from the process and feedback loops that inform people how

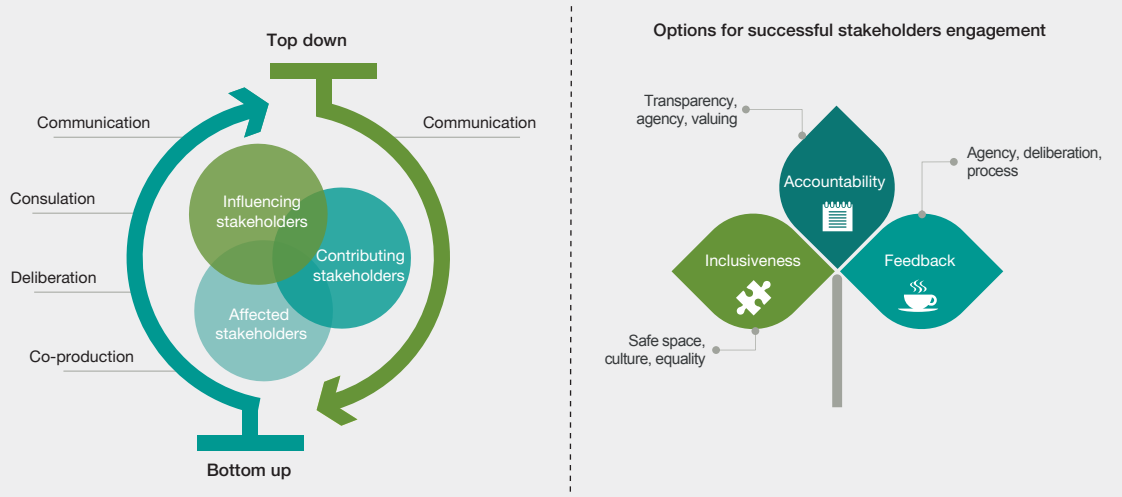


Figure 6 16 **Options for successful engagement of stakeholders and Indigenous Peoples and local communities.**

This figure shows the different options available to engage with stakeholders and Indigenous Peoples and local communities (left), and a focus on empowerment (right). Adapted from Reed *et al.* (2018), https://doi.org/10.1111/rec.12541, under copyright 2017 Society for Ecological Restoration and Bell and Reed (2022), https://doi.org/10.1093/cdj/bsab018, under license CC BY 4.0.

their knowledge has been used to manage invasive alien species in their area or sector; **Figure 6.16**).

An understanding of stakeholders and Indigenous Peoples and local communities' influences and interests, how each are likely to be involved in different invasion stages, and their participation as equal partners, can therefore contribute to the success of any attempt to represent, empower people and co-design biological invasion management and governance. If communicative and consultative approaches can deliver significant benefits (Shackleton, Adriaens, *et al.,* 2019), co-productive approaches may be more appropriate than hierarchical governance approaches, especially in contexts where there is significant conflict of interest or mistrust between stakeholders.

6.4.3 Coordination, collaboration and Indigenous Peoples and local communities[11]

Indigenous Peoples and local communities often have detailed knowledge of invasive alien species (**Chapter 1**, **section 1.6.7.1**), including their dynamics (**Chapter 2**, **Box 2.6**), drivers (**Chapter 3**, **Box 3.14**), impacts (**Chapter 4**, **section 4.6**), and the ability to manage or adapt to their presence (**Chapter 5**). Many Indigenous Peoples and local communities also have their own customary governance systems and institutions that may already be working to support management of biological invasions. There have indeed been many cases where management plans or techniques have negatively impacted the food security, culture and values of Indigenous Peoples and local communities (IPBES, 2022). This section will discuss efforts to avoid this scenario.

6.4.3.1 Rights of Indigenous Peoples and local communities

In some contexts, there are legal obligations to recognize the rights of Indigenous Peoples and local communities to manage their own lands and waters. The adoption of the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) in 2007 has provided a specific framework for engaging with Indigenous Peoples. Free, prior and informed consent (FPIC) is a specific right that pertains to Indigenous Peoples, which allows them to give or withhold consent for a project that may affect them or their territories, which could include efforts to manage or eradicate invasive alien species. Furthermore, free prior and informed consent enables them to negotiate the conditions under which a project will be designed, implemented, monitored and evaluated. The framework is less clear for "local communities", but some countries have specific legal frameworks for working with specific groups.

Many Indigenous Peoples and local communities have requested that their own customary governance systems and institutions be recognized within efforts to manage biological invasions, recognizing that these systems can be strengthened and, in some cases, revitalized by support from outside institutions (IPBES, 2022). Recognition and clarification of land tenure, including access and ownership of land, waters and biological resources can support Indigenous Peoples and local communities to manage biological invasions (IPBES, 2022; Kamelamela *et al.,* 2022).

These specific knowledge and governance systems and normative frameworks often mean that Indigenous Peoples and local communities do not wish to be considered or approached in the same ways as other "stakeholders" discussed above, as such broad multi-stakeholder processes can often serve to diminish their participation and obscure their rights and goals. A deeper engagement with their knowledge and customary governance systems within rights-based frameworks and in accordance with national legislation can therefore benefit both communities' good quality of life and biological invasions management strategies.

6.4.3.2 Co-production of Indigenous Peoples and local communities planning and Biocultural community protocols

Despite the reasons for engaging with Indigenous Peoples and local communities and their knowledge and governance systems discussed above, many discussions of Indigenous Peoples and local communities rely on a "vulnerability narrative" which considers them as passive victims of damage from environmental change. This can lead to policies and management actions that interfere with community wellbeing and do not support capacity-building and cultural continuity (Reo *et al.,* 2017; **Chapter 4**, **Box 4.14**).

Many cases (70 per cent of reviewed cases)[11] suggest that, even where collaborations between outsiders and Indigenous Peoples and local communities are reported to be successful, they do not necessarily consider Indigenous and local knowledge and governance. Some cases report that outsiders tend to focus instead on teaching Indigenous Peoples and local communities about management of invasive alien species using scientific methods. This can cause the loss of knowledge and important cultural practices of Indigenous Peoples (Sillitoe, 1998), as well as undermine long-term management success. There are however positive examples of the inclusion of Indigenous and local knowledge, community governance and institutions in the management of biological invasions.[11]

11. Data management report available at: https://doi.org/10.5281/zenodo.5760266

For example, forest scientists partnered with Indigenous Peoples and local communities in Michigan, United States to co-design invasive alien species control experiments using traditional ecological knowledge (Poland *et al.,* 2017). Indigenous Peoples and local communities were involved in decision-making processes for weed control in Western Australia. Rangers consulted Indigenous Peoples and local communities' elders about their work eradicating weeds and used "place centred" methods (Bach *et al.,* 2019).

Overall, key aspects that Indigenous Peoples and local communities have highlighted in relation to successful co-production and co-management include respect for community knowledge, institutions and protocols, allowing enough time to build trusting relationships, and broad distribution of benefits from biological invasion management, which do not need to be financial and can include capacity-building in research and management.[11]

Some Indigenous and local communities have developed biocultural community protocols (**Glossary**), documents that consider their values, procedures and priorities to frame how they wish to be engaged in projects that impact them. They set out rights and responsibilities under customary, state and international law as the basis for engaging with other stakeholders (Natural Justice, 2022). Biocultural community protocols could be a foundation for discussions with communities on policies related to managing invasive alien species and restoring ecosystems. For instance, in Hawaii, a biocultural community protocol has been developed to support the successful ecosystem restoration of the Pu'uwa'awa'a Community-Based Subsistence Forest Area (Kamelamela *et al.,* 2022). Co-production of planning and decision-making, or support of existing Indigenous Peoples and local communities' invasive alien species management systems could indeed benefit communities beyond biological invasions management. It provides recognition of their knowledge systems and incentives to continue or revitalize traditional monitoring, management and knowledge transmission and simultaneously enhances the efficacy of biological invasions management (IPBES, 2021, 2022)

6.4.4 Governance networks for collective action

Engaging with stakeholders and Indigenous Peoples and local communities, and considering diverse actors involved in governance for biological invasions (**section 6.2.3.3**) can be achieved by establishing informal or formal mechanisms for collective action (**Glossary**). Simply recognizing this need does not mean that collective action will happen, nor that collective initiatives and arrangements will be effective at solving the problems at hand (Koontz & Thomas, 2006; Lubell, 2004). Collective action outcomes often emerge through self-organization (where overall organization arises spontaneously from local interactions) – as when numerous individual managers acting independently apply cultural controls that together change the invasibility of landscapes (P. L. Howard, 2019). As demonstrated in an Australian rural landscape through a Landcare program, successful collective action emerged through the key role of a leader, building trust and social norms in the community, along with contracts that strengthened commitment and steered action towards the control of high priority invasive alien species (McKiernan, 2018).

Collective action is also often jointly planned and executed, based on place-based or culturally-based rules and norms where community members jointly assume responsibility for invasive species management (e.g., Graham *et al.,* 2019; Lien *et al.,* 2021; Lubeck *et al.,* 2019; Sullivan *et al.,* 2017; Yung *et al.,* 2015). However, the conditions required to engage in collective action are often absent; for example, an awareness of cross-boundary relationships, beliefs and expectations that other people will carry out appropriate actions, an absence of effective leadership or low confidence that collective efforts will be effective (Bodin *et al.,* 2019; Lubeck *et al.,* 2019; **Figure 6.24** in **section 6.7.3**). Even in cases where collective action mechanisms are in place and function well, there is often a need to support or coordinate such actions at higher levels of governance. Research has shown that a number of micro-interventions during community engagement can change opinions, beliefs and commitment leading to improved management outcomes (Niemiec *et al.,* 2019).

6.4.4.1 Coordination *versus* cooperation: challenges and options

It is important to differentiate biological invasion problems that are more related with coordination from those requiring cooperation (Bodin *et al.,* 2020). Effective coordination depends on finding ways for stakeholders who generally share the same viewpoints and interests to agree on how best to address a problem. This mainly involves mechanisms "to accomplish a generally agreed upon objective through, for example, efficient resource allocation, synchronization of different activities and a suitable division of labour for common tasks" (Bodin *et al.,* 2020). This is the case, for example, with *Fusarium* dieback (an invasive alien pathogen vectored by beetles that causes disease that damages avocado and more than 39 other tree species) in California, United States, which quickly prompted numerous government and non-government stakeholders who cooperate at different scales with very similar objectives to coordinate and confront the issue and develop a cohesive state-wide strategy (Lynch, 2020). **Box 6.14** presents another example of a governance network solution to achieve coordination between stakeholders who held similar interests in invasive

Box 6 14 Coordinating American mink eradication in North East Scotland through community partnerships and adaptive management.

In Northeast Scotland, when small-scale American mink removal projects failed due to mink recolonization from surrounding uncontrolled areas, adaptive-coordination strategies (**Table 6.1**; **section 6.2.3.1(4)**) were devised and implemented to eradicate mink over a large area. Due to uncertainties about the size of the mink population, mink's dispersal capacity, and the volunteer resources that would be needed and available to effectuate mink eradication, an adaptive management approach was developed involving formal coordination between diverse stakeholders. The project was initiated by scientists and supported by a government agency, a national park authority and local fisheries boards, all of whom shared an interest in mink eradication.

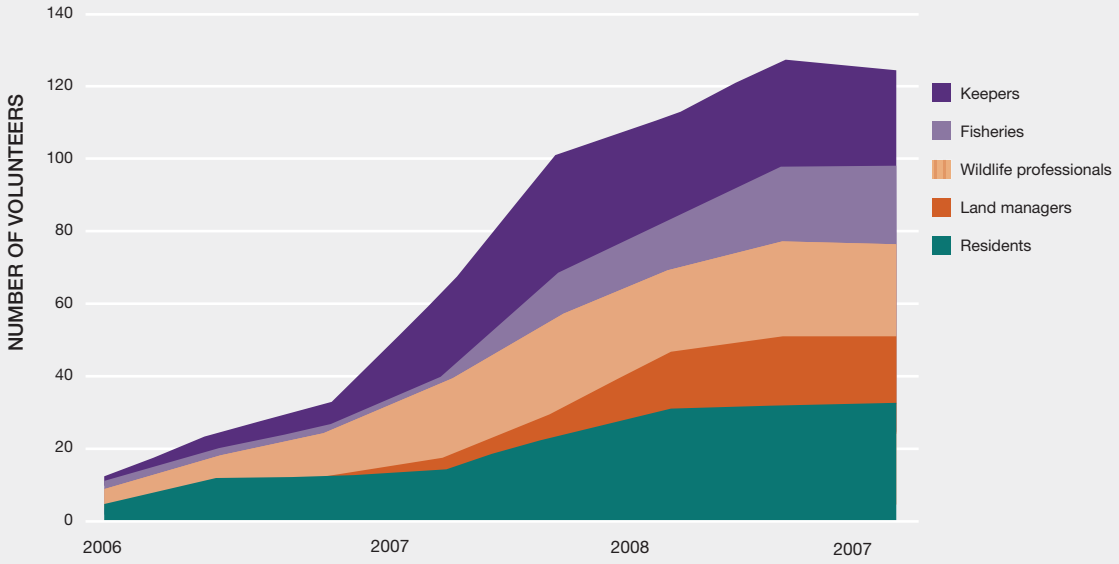


Figure 6 17 **Cumulative mink captures over the entire project area showing an increasing number of captures by volunteers, with the total number of active volunteers.**

Throughout the project shown by category. Source: Bryce *et al.* (2011), https://doi.org/10.1016/j.biocon.2010.10.013, under license CC BY 4.0.

Together, a coordinated coalition of trained volunteers was created to detect and trap mink **(Figure 6.17)**. These groups created a formal partnership that funded the project and provided in-kind contributions. The project achieved "multi-scale mink removal over 10570 km^2 with 10000 appearing to ¬be free of breeding mink 3 years after inception." Over time, the number of the local volunteers detecting and trapping mink grew – especially among local residents, land managers and wildlife professionals (Lambin *et al.,* 2012). "The defining factors underpinning the success of the project are strong volunteer involvement, efficient and systematic methods of monitoring and control, an adaptive approach to suit local conditions, the strategic use of topography to minimize recolonization and an ambitious vision; elements that are applicable to other invasive alien species and areas. It is a strong testament to what can be achieved when empowering local communities to take a stake in their local biodiversity and thus reason for optimism that the tide of invasion can be rolled back on a large scale where the convergent interest of local communities can be harnessed" (Bryce *et al.,* 2011).

alien vertebrate eradication, and where adaptive responses were needed to overcome uncertainties.

However, in many cases, invasive alien species present a cooperation problem rather than a coordination problem, as they involve stakeholders "with opposing interests seeking and finding agreeable ways to solve collective problems and dilemmas where their different interests are at stake, and where a solution often requires actors to make some sacrifices" (Bodin *et al.,* 2020). Thus, cooperation is associated with conflicts of interest, inherent trade-offs and subsequent tensions among actors. This was the case, for example, with the Panama Tropical Race 4 incursion in banana plantations in north Queensland, Australia. Many banana growers argued that their value- and cost-losses were not sufficiently compensated when implementing

state-mandated biosecurity measures, leading ultimately to negotiations between the growers' industry body and the government on new standards and guidelines for production post-infection (Maclean *et al.,* 2018). Very often, there are multiple groups of "outcome winners" and "cost, value and collateral" losers whose interests and perceptions of invasive species are in conflict. Compared with coordination, cooperation is thus associated with higher risk for all of the actors involved (Berardo & Scholz, 2010). Thus, there is much greater need for processes of engagement that involve consensus-building, negotiation, knowledge integration and development of trust.

6.4.4.2 Tailoring collaborative governance networks

Collaborative governance networks consist of individuals and organizations that have come together to solve common problems that would be difficult or even impossible for a single organization to address alone (**section 6.2.3.3**). Governance itself can be characterized as a "polycentric network" of relations between government and non-governmental stakeholders whose knowledge, behaviour or interests are involved in different aspects of environmental policy-making (Berardo & Lubell, 2019; Bodin, 2017; Bodin *et al.,* 2017; Kluger *et al.,* 2020; Lubell, 2013). Such networks span a range of types, from "completely decentralized with all participants connected, to completely centralized with all collaboration brokered by a single organization" (Lubell *et al.,* 2017). Multiple types of networks across this span are likely to be needed for progress towards and implementation of integrated governance for biological invasions in each context (**section 6.2.3.1**).

The distinction between coordination and cooperation has strong implications for the type of governance network and collective action arrangements that are, more or less, suited to the tasks at hand. Such networks typically take three different forms, each with its own advantages and limitations (Provan & Kenis, 2008; **section 6.2.3.3**):

1. In participant-governed networks, there is no obvious central leading actor – all actors contribute fairly and equally to the collective effort. These networks tend to be dense (there are many social ties between the participants) and can work very effectively, but typically suffer when the number of members is high, since the lack of a hierarchical structure makes it difficult to coordinate numerous actors.

2. The second form is where one or a few of the participating actors take on a leading role, and the network subsequently takes a centralized "hub-and-spoke" structure where the leaders are directly connected to all or most other actors, thus becoming the hubs in a wheel-shaped network.

3. In the third form of network, a dedicated coordinating actor (a "Networker" stakeholder and a representative of Indigenous Peoples and local communities) is appointed as the central leader – a network administrative organization (NAO), also referred to as a bridging organization (Crona & Parker, 2012) or a collaborative institution (Lubell *et al.,* 2010). The network administrative organization can be created by the network members or provided or imposed externally. An external actor that wants to build a governance network to address invasive alien species could create a network administrative organization either to enhance and strengthen (and/or possibly control) existing governance networks, or to build a governance network from scratch.

An example of a successful network administrative organization (NAO)-led network management is found in the management of a hybrid between introduced *Sporobolus alterniflorus* (smooth cordgrass) and native *Sporobolus foliosus* (California cordgrass) in San Francisco Bay, a multi-tenure area where government agencies, private landowners and others are involved in efforts to eradicate this ecosystem engineer that will reinfest if it is not eliminated in all areas of the Bay. The management of *Sporobolus* is governed by a collaborative partnership between private landowners, government agencies and other stakeholders called the Invasive Spartina Project. The California State Coastal Conservancy, an agency whose mission is to protect the coast, and an environmental consultant founded the project with state funding. Together they serve as "central brokers" that coordinate the activities of stakeholders as a NAO. The project has "successfully removed 95% of invasive *Spartina [Sporobolus]*, and is now engaged in suppressing re-invasion and ecological restoration…the [project] has been very effective in comparison with other local collaborative partnerships" (Lubell *et al.,* 2017). However, such arrangements may not be effective for invasive alien species that have very different ecological dynamics, such as with very fast spreading marine species, where a myriad of organizations and individuals would be involved at short notice.

Hybrid networks may consist, for example, of bottom-up, participant-led initiatives that are provided with support and coordinated by a "networker" stakeholder. This is the case with the award-winning Victoria Rabbit Action Network (VRAN), which was developed in Victoria, Australia, in response to the failure of a largely top-down regulation and enforcement regime (L. B. Adams, 2014; L. B. Adams *et al.,* 2019; **Box 6.15**). In Central Burnett, Queensland, Australia, when the state reduced support for management of *Bactrocera tryoni* (Queensland fruit fly) and encouraged greater grower self-reliance, growers and their industry body formed an Area-Wide Management Committee, which acted as a network administrative

Box 6 15 Case study illustrating a successful expansion and temporal shift in governance from top-down regulation to community-led action.

A case that demonstrates the shift from top-down, regulation and enforcement based governance toward a government-supported, community based approach is found in a United Nations Award-winning initiative developed to manage one of Australia's most costly invasive vertebrates, the European rabbit (L. B. Adams, 2014). Prior to the development of the programme, information and power asymmetries limited the effectiveness of rabbit management, as those responsible for on-the-ground control – landowners and community organizations – were "kept at arm's length," at the same time that conflicting perspectives on the need to control rabbits, animal welfare concerns and changes in land use presented barriers to top-down regulation and targeted programmes (Reid *et al.,* 2019). The Victorian Rabbit Action Network (VRAN) was developed by the National Rabbit Facilitator collaborating with groups involved in rabbit management, and adopted "systems-thinking…to understand how rabbit management works from a range of perspectives, test assumptions, and…develop and test strategy ideas" (L. B. Adams, 2014). The initiative focused on building networks and improving information flows and knowledge sharing through knowledge brokers. Communities were seen as sources of "socio-political and technological innovation, as opposed to consumers" and innovation was stimulated through competitive grants (Reid *et al.,* 2019). A democratic, participatory approach not only allowed a diversity of perspectives and experiences to be shared – conflicts inherent in the process "served as a driver of innovation, in that differing perspectives were discussed in respectful and authentic ways, allowing the emergence of innovative ideas and new ways of working together." The evaluation by Allen (2017) of VRAN's activities found that communities were exercising their agency and acting collectively, with decreased reliance on government (Allen, 2017). In four years, over 5,300 people were surveyed and 84 per cent of respondents were using an integrated rabbit management approach. In part due to this success, an additional programme was introduced in 2017 to support coordinated community-led action around the use of a new strain of calcivirus (rabbit haemorrhagic disease virus, RHDV K5) for biocontrol (Reid *et al.,* 2019). Unfortunately, overall outcomes on rabbit numbers and impact were not monitored.

Checklist of principles and requirements for successful community-led action on rabbits (L. B. Adams, 2014):

1. Leadership with empowered community groups
2. A community owned vision, philosophy, purpose and narrative
3. A partnership approach among the institutions and groups involved in rabbit management, with joint decision-making, responsibility, action and resourcing
4. Coordinated planning and action guided by a strategy, with understanding of:
   - **a.** Community concerns and motivations that are generating interest in rabbit management
   - **b.** What the community seeks to achieve and can realistically achieve – short and longer-term
   - **c.** Current management practices: adaptive natural resource management, integrated pest management (**Glossary**), consideration of longer-term options to reduce rabbit impacts which goes beyond a focus on reducing rabbit populations, consideration of regulation and compliance requirements, consideration of options to assess and monitor a rabbit problem and rabbit impacts, consideration of the short and longer-term benefits and costs of different control options
   - **d.** The available resources and tools that can assist community planning, action, learning, awareness, education, leadership development and innovation
   - **e.** How best to navigate institutional arrangements that affect community capacity and action on rabbits
   - **f.** How best to focus resources and effort
5. Demonstration and celebration of results and success linked to the community's vision and purpose
6. Government support for compliance
7. Recognition that community-led action and collaborative strategies involving all groups with rabbit management responsibilities are critical for success

organization (NAO), together with government staff, local growers, the industry body and other local stakeholders. Among other activities, it carried out management trials, fine-tuned management to suit individual grower operations, provided resources for treatments in towns funded by voluntary grower contributions, transferred expert knowledge and engaged in awareness raising. Reported results were "spectacular" – peak trap catches prior to the new governance arrangements were 240 flies per trap each day, reducing to one fly within a few years (Kruger, 2016).

With respect to the relation between governance networks and cooperation or collaboration problems, it is argued that denser, overlapping networks reduce monitoring and sanctioning costs involved in resolving collective action problems, for example, if some members freeride (e.g., allowing other participants to do the bulk of the work) or do not cooperate. Coordination problems, on the other hand, favour more "open" network structures. However, "the advantage of central coordination declines with the complexity and need for consultation involved in crafting solutions" (Berardo & Scholz, 2010).

Participant-governed networks are more effective at addressing cooperation problems (albeit only for smaller networks), while centralized networks (with or without a network administrative organization) are better suited for coordination problems (Bodin, 2017). Recent research has nuanced the proposed relationship between network structures and coordination/cooperation problems by explicitly accounting for trust, costs and risks as intermediate factors (Bodin *et al.,* 2020). More research in varied biogeographic and socio-economic contexts will contribute to improve governance networks.

6.4.4.3 Collective action

Governance for biological invasions is in part a collective action problem with coordination or collaboration solutions (Hershdorfer *et al.,* 2007; Epanchin-Niell *et al.,* 2010; McLeod & Saunders, 2011; Bagavathiannan *et al.,* 2019) including, for example, public-private partnerships (Mato-Amboage *et al.,* 2019). As outlined earlier, the mobility of invasive alien species means that prevention of their movement and management of established populations can benefit from collaboration and coordination across property and jurisdictional boundaries (Graham, 2014; Yung *et al.,* 2015; T. M. Howard *et al.,* 2018). Achieving such cooperation is challenging because diverse actors have varying levels of interest, skills, resources, capacity and time to commit to management of biological invasions (Donaldson & Mudd, 2010; Graham, 2013; Ma *et al.,* 2018; Kropf *et al.,* 2020). Successful collective action can be achieved through stakeholder and Indigenous Peoples and local communities networks. Social norms and trust can be established to develop a common understanding of the problem, agree on a common goal, identify measures of success and encourage participation in individual and group activities (Stallman & James, 2015; Niemiec *et al.,* 2016; Graham & Rogers, 2017; T. M. Howard *et al.,* 2018; Bagavathiannan *et al.,* 2019). There are sets of useful questions that are consistent across these cooperative invasive alien species management initiatives **(Table 6.9)**. While consideration of these factors listed in **Table 6.9** does not guarantee success, the questions do provide practical insights into what collective action offers for improving the governance for biological invasions into the future.

Table 6 9 **Collective action questions towards improved governance for biological invasions.**

Leadership	Who will lead the collective action initiative?
Working relationships	Who to include?
	Are there existing relationships among participants?
	How can trust be built among group members?
Shared goal	What is the shared goal?
	What are the ecological, economic and social dimensions of the goal? (What motivates one person may not motivate another)
	Does the goal focus on a single species or a whole ecological community?
	What area does the goal cover?
	What does success look like?
Pooling resources	What are the asymmetries in the programme?
	Who needs support?
	How can such support be provided?
	Where will resources come from over the short and long term?
Coordination	How can disparate efforts be connected?
	Who will make the connections?
	What support can be provided across initiatives?
	How will gaps be filled?

6.4.4.4 Applications of network analysis to support adaptive-collaborative governance

Network analysis of governance structures and stakeholders is useful for understanding and improving cooperation, coordination and information flows across a large number of actors and organizations engaged in biosecurity. As an example, in Australia, there is a "recognition that government players are neither resourced sufficiently to fill all required roles and responsibilities, nor necessarily the most capable of filling all roles…biosecurity now turns to multiple purpose networks that seek to mesh diverse tasks such as surveillance, policy development, response to incursion, awareness building, and research and development" (McAllister *et al.,* 2020). An independent marine pest network was formed to provide continuous communication for surveillance and rapid response (i.e., a "suite of organizational interactions that emerge around the Government's Marine Pest Sectoral Committee"), and includes scientists, industry and members of the public. The network is focused on communication, surveillance and engagement but does not manage incursions. Social network analysis showed that the "network is well-structured for information dissemination and there is evidence that nongovernment actors already play some role in integrating and brokering information", however, improvement is required, as it was found that, while information is provided to the community, there is a "near absence of ties for receiving information from the community" (McAllister *et al.,* 2020).

Adaptive-collaborative governance thus involves multi-level and multi-actor coordination and collaboration based on knowledge and disciplinary integration, experimentation, monitoring, the use of the best available technology and social learning (Kirkfeldt, 2019; **section 6.2.3.1(4)**). Many frameworks have been developed that explicitly consider the interactions between social and ecological systems. Not all frameworks, however, give equal emphasis to humans and ecosystems or their dynamic interactions (Binder *et al.,* 2013). Those that do, insist that involving stakeholders in collaborative environmental governance of such systems is imperative. Some of these approaches focus on networks of human-ecological interdependencies either within bounded geographical areas or, more often, across geographical barriers or boundaries and governance realms. This includes, for example, marine protected networks that usually involve large geographic areas, ecological connectivity, and many different government agencies and stakeholder and Indigenous Peoples and local communities groups (S. M. Alexander *et al.,* 2017).

Network analysis may be used to examine both the "fit" between governance and ecological scales and processes and the need to achieve coordination and collaboration among a large number of government agencies and stakeholders. Multilevel horizontal and vertical governance ties bring actors together to form multilevel (local to national) networks to coordinate, collaborate and share knowledge that is needed, e.g., to address a lionfish invasion in Jamaica's marine protected areas **(Box 6.16)**. Another example of how collaborative governance networks can be established to achieve greater ecological and governance fit is presented by network administrative organization-led coordination of *Phragmites australis* (common reed) management in the Great Lakes, United States **(Box 6.16)**.

Box 6 16 **Two examples of network analysis and adaptive-collaborative governance to strengthen the prevention and control of invasive alien species.**

(1) Horizontal and vertical governance ties to achieve social–ecological fit in response to a lionfish invasion an emerging marine reserve network in Jamaica.

Invasive alien species context: *Pterois volitans* (red lionfish) and *Pterois miles* (lionfish) favour near-shore reef habitat and are now prevalent across the Caribbean, Gulf of Mexico and Western Atlantic. First sited in the Bahamas in 2004, populations and distributions expanded rapidly (Côté *et al.,* 2013). By 2009, their range had expanded to Jamaica, with populations becoming established around the entire island within a year (Schofield, 2009). With no natural predators, lionfish consume a significant amount of especially juvenile native fish, depleting near-shore fisheries and coastal biodiversity in Jamaica. A study in the Bahamas found that, over a 2-year period, an increase in lionfish biomass coincided with a 65 per cent decrease in the biomass of 42 native species (Green *et al.,* 2012).

Governance context: The Jamaican Government has established, to date, 17 "special fishery conservation areas" (i.e., marine no-take areas that range from about 1 km^2 to 18.73 km^2). The majority of these conservation areas are close to small coastal communities with active small-scale and artisanal fisheries that use mixed gear (e.g., fish traps, spear guns) and target multiple species (e.g., conch, lobster, reef fish). It also established co-management arrangements with local non-governmental organizations and/or fisher cooperatives that devolve roles and responsibilities (e.g., monitoring) associated with the day-to-day management of these marine reserves (S. M. Alexander *et al.,* 2015).

Box 6 16

A multi-actor network: Social network analysis revealed that the governance structure of the Special Fishery Conservation Areas is constituted of ties between actors, including government and non-governmental organizations (S. M. Alexander *et al.,* 2016). Many of the ties emerged through one of the following three processes: (i) formal partnerships (e.g., co-management arrangements, capacity-building); (ii) personal connections and relationships; and (iii) joint membership on committees, boards and projects. For example, the Lionfish Project – funded by the Global Environment Facility (GEF) – fostered network ties between government agencies, non-governmental organizations, community-based organizations and private resorts. Collectively, the resulting governance network provided a critical foundation for an island-wide lionfish monitoring and culling programme. Multi-actor network ties connect actors horizontally across local sites of action and management that are geographically distributed, which is essential when effective responses to a biological invasion occurs simultaneously across sites. However, research revealed a lack of strong ties and information sharing between those local level management organizations with a mandate to manage one or more special fishery conservation areas. Multi-actor governance networks that span sectors, departments and agencies can contribute to increased coordination, which is central for effectively responding to and governing biological invasions and the multiple dimensions of socioecological fit associated with marine protected areas. Multi-level network ties can be central to linking action at multiple scales and tightening feedback, which are critical processes for effectively responding to and managing biological invasions. Multilevel linkages played the greatest role in enhancing fit in the marine reserve network. However, the long-term propensity of the multi-actor and multilevel networks to enhance social–ecological fit is uncertain given the prevalence of weak social ties, lack of a culture of information sharing and collaboration and limited financial resources.

(2) An adaptive collaborative governance approach to *Phragmites australis* (common reed) management in the Great Lakes, United States.

An example of adaptive collaborative governance is presented by the Great Lakes Restoration Initiative,[12] which supports a basin-wide initiative called the Great Lakes *Phragmites* Collaborative (Braun *et al.,* 2016). *Phragmites australis* is an invasive alien wetland species that affects ecosystem functions, biodiversity and social and economic values, and threatens restoration, generating large financial burdens for land management. A total of $16 million was invested in the Great Lakes Restoration Initiative from 2010-2015 to support the Great Lakes *Phragmites* Collaborative, which was developed to address numerous barriers to *Phragmites australis* management, including a lack of organized communication among managers and between managers and researchers; a failure to address *Phragmites australis* at a landscape scale (multi-state and bi-regional), and a lack of a common agenda or strategic plan in a context where stakeholders working independently were producing isolated impacts or duplicating efforts, leaving gaps that undermined management.

As a "neutral facilitating" entity, the Great Lakes *Phragmites* Collaborative serves as a regional representative for impacted stakeholders, providing support to develop common agendas, mutually reinforce activities and share measurements for assessing progress. An advisory committee represents a diversity of disciplines and expertise across different state and non-state organizations and geographical areas. The committee articulated a vision statement and common agenda that will be elaborated on, as much as possible, by consensus, which also includes support for individual initiatives. An adaptive collaborative process "involves stakeholders progressing toward a goal through a structure that facilitates mutually reinforcing activities and regular feedback… aligned efforts, support for discovery of new practices, and widespread adaptation of successful practices…an adaptive management technique because it promotes learning and adaptation." A shared measurement system is considered to be essential for adaptive management – to assess progress, align individual strategies with landscape-level goals, and provide empirical information for adaptation. It showcases best management practices and lessons learned, and responds to needs identified in a stakeholder and Indigenous Peoples and local communities survey by providing access to information resources, information sharing and technology transfer (Braun *et al.,* 2016).

Network analysis can also be applied to both the biophysical and social processes entailed in pathways of introduction or spread of invasive pathogens, plants, or mammals, which includes international and domestic transport and other types of movements involving stakeholders, agents (e.g., ships), events and species or hosts that interact in space and time (D. C. Cook *et al.,* 2010; Hulme *et al.,* 2018; Lansink *et al.,* 2018). Within-sector (e.g., livestock, forestry) network analysis is related to the movement of invasive vectors and hosts through chains that link vector stakeholders and Indigenous Peoples and local communities with contributors in supply or value chains (**Glossary**). The FAO promotes such analysis to provide an evidence-base for animal diseases epidemiology to inform risk analysis and develop strategic plans for disease control and surveillance (FAO, 2011). Contact networks (i.e., networks and linkages in value chains that connect production systems, markets and

12. https://www.greatlakesphragmites.net/

consumers) can favour the transmission of contagious diseases within and between sectors, and need to be taken into account in the development of risk management strategies for the control and prevention of animal diseases (FAO, 2011). The input of a wide range of stakeholders is essential for this network analysis to be effective.

6.4.4.5 Challenges of collaborative governance approaches and success factors

Governance approaches themselves can be a significant source of conflict in invasive species management, particularly when various groups of influencers or interested stakeholders and Indigenous Peoples and local communities are not consulted, their knowledge is not taken into account, or they are not involved in implementation actions that affect them (Crowley *et al.,* 2017a; Estévez *et al.,* 2015; Lynch, 2020). Adaptive-collaborative management benefits from good governance, and vice versa. Plummer *et al.* (2013) examined the literature on adaptive collaborative management for governance content and found multiple relationships: among others, good governance is necessary to facilitate adaptive collaborative management, which helps facilitate a shift to good governance and can operationalize governance, while stressing multi-level, multi-sector and multi-stakeholder and Indigenous Peoples and local communities engagement (**section 6.7**). Common themes that emerge include the need for: accountability and legitimacy, the involvement of diverse stakeholder groups and Indigenous Peoples and local communities and bridging organizations, the need to achieve organizational fit, interplay and scale; for adaptiveness, flexibility and learning, as well as social learning and knowledge sharing[13] (drawn together in **section 6.7**).

In addition to giving citizens and stakeholders a voice in decisions that affect them, it is claimed that collaborative approaches to environmental governance can reduce conflict, build trust and facilitate learning among citizens and stakeholders, increasing the likelihood that decisions are implemented on the ground and over the long-term (e.g., Beierle, 2002; De Vente *et al.,* 2016; Derak *et al.,* 2018; M. S. Reed, 2008; M. S. Reed *et al.,* 2018). However, stakeholders and Indigenous Peoples and local communities involvement can only be successful when tailored to the problem and context (**section 6.4.1**). In some cases, stakeholders and Indigenous Peoples and local communities need to be involved in "deeper, two-way, co-productive engagement (possibly over long time-scales)" (Shackleton, Adriaens, *et al.,* 2019). This may be the case, for example, when coordination of the management of biological invasions occurs across multiple land tenures or land-use settings (Bryce *et al.,* 2011; Shackleton *et al.,* 2015), or where cooperation problems are evident and thus the potential for conflict or lack of cooperation is high. These conditions may call for stakeholder and Indigenous Peoples and local communities' involvement in the co-design or co-development of risk assessments, strategies and management approaches, co-creation of knowledge and co-implementation.

Several factors seem to be key to the success of adaptive-collaborative governance for biological invasions. One of them is the breadth of involvement of stakeholders and Indigenous Peoples and local communities, ensuring that all stakeholders with influence and interests are included lends governance the legitimacy it needs for policy implementation. Another factor is the deliberative and transparent nature of the collaborative process, as well as its ability to account for and manage power imbalances and conflicts (Newig *et al.,* 2018). Finally, high levels of social interaction among the participating actors favour positive outcomes and help to build commitments, knowledge and trust (S. M. Alexander *et al.,* 2018; Bodin, 2017; Newig *et al.,* 2018). These in turn are instrumental for collectively addressing coordination and collaboration problems. In other words, one key factor that is needed to achieve successful collective action is to build appropriate governance networks where relevant actors, individuals and/or organizations are included and engaged with each other (DeFries & Nagendra, 2017). Other critical factors that affect the effectiveness of networks include consensus around goals and the need for "network competencies," or specializations, among the network's participants, such as research competence (Lubell *et al.,* 2017).

Engagement with stakeholders and Indigenous Peoples and local communities is therefore an essential element of integrated governance of biological invasions (**section 6.7**). While it may not be possible, due to time or resource constraints, to develop effective adaptive-collaborate governance networks, deep stakeholder and Indigenous Peoples and local communities engagement can be built into any governance and policy development approach.

13. Data management report available at: https://zenodo.org/doi/10.5281/zenodo.5762739

6.5 ECONOMIC AND FINANCIAL OPTIONS

Although the costs associated with invasive alien species have been estimated to be in the trillions of dollars globally (Diagne *et al.,* 2021; **Chapter 4**, **Box 4.13**), the economic, political and financial systems have not yet sufficiently internalized these estimates. Therefore, biological invasions remains largely unaddressed at the national and international level (Pimentel *et al.,* 2005). Many impacts are unrecorded due to serious data gaps in several regions and there are ongoing methodological challenges about how to estimate social costs. It is clear, however, that the costs of impacts far outweigh the costs of management (**Chapter 5**, **section 5.5.7**; Diagne *et al.,* 2021).

Of particular concern are the indirect impacts of invasive alien species, as they are both inherently difficult to quantify and, in some cases, magnified under the prism of climate change (Mainka & Howard, 2010). Invasive alien species pose an enormous risk to good quality of life through their effects on social, economic and environmental systems (**Chapter 4**, **sections 4.5** and **4.6.3**). In some cases, such as invasive alien species-related agricultural losses, these effects can potentially destabilize socioeconomic and democratic structures by causing famine and social unrest (Goss *et al.,* 2014; Singh & Kaur, 2002).

These indirect impacts are yet to be incorporated into national accounting measurements of economic growth (e.g., gross domestic product (GDP) and gross national product (GNP)). For example, economic growth measures include exports as a benefit but ignore possible damage from potential unintentional species introductions. Several researchers and governments have recognized the importance of accounting for economic activity's environmental impact, called green national accounting (Fenichel & Abbott, 2014; Kubiszewski *et al.,* 2013). Progress in green national accounting has been seen in the Genuine Progress Indicator (Kubiszewski *et al.,* 2013), the Index of Sustainable Economic Welfare (Beça & Santos, 2010; Stockhammer *et al.,* 1997) and the Gross National Happiness measure (Ura *et al.,* 2012). Nonetheless, most of these green national accounting measures (aside from Beça & Santos, 2010) continue to ignore invasive alien species, which is a significant oversight. According to a recent report from the CBD on the resources needed to implement the Kunming-Montreal Global Biodiversity Framework, the cost of the continuous management of alien invasive species is estimated at $36 billion to $84 billion per year, depending on the assumptions used in the calculations (CBD, 2021b). To halt and reverse the trends of biodiversity loss and impacts on good quality of life, it is urgent to make the case for the importance of invasive alien species in the larger context of global biodiversity change (Mooney & Hobbs, 2000); cross-sector policy, coordination and collaboration have been identified as essential to invasive alien species prevention and control (**sections 6.2** and **6.3**).

Identifying financial and economic mechanisms to address invasive alien species is challenging for three principal reasons:

1. they affect public goods, which complicates the important task of defining responsibilities (Perrings *et al.,* 2002; **section 6.3.1.1**);

2. many of the costs and benefits of investment in invasive alien species management are non-market values (Perrings *et al.,* 2010), in some cases affecting values that cannot be monetized thereby limiting their consideration in economic flows and return on investment analyses (Auerbach *et al.,* 2014), and their use as arguments for generating resources and investment;

3. the ambiguous property rights of some goods and services that are affected by invasive alien species make it extremely difficult to implement public policy, legislation and regulatory mechanisms to protect these goods and services (Reichard *et al.,* 2005).

These three characteristics, compounded by the probabilistic nature of a successful invasion event (Fournier *et al.,* 2019) and the lag time that often separates an introduction from a successful invasion (Essl *et al.,* 2011), make it difficult to internalize the effects of invasive alien species, and therefore argue successfully for investing the resources necessary to adequately confront this global issue in a given region.

This IPBES assessment of invasive alien species cannot offer a comprehensive global review of existing financial and economic mechanisms, nor can it define a road map for success in the management of biological invasions (**section 6.2**). Rather, it presents some of the economic instruments available to finance different aspects of the invasion process, including prevention, eradication, containment, mitigation and restoration. The IPBES assessment of invasive alien species also examines some of the challenges, benefits, appropriateness and implications of adopting these instruments in different contexts and at various scales. It provides some insights for generating the economic incentives and deterrents that support a sustainable global effort to address the problem of invasive alien species in a more coordinated and better-financed manner. Some of the options presented are likely to resonate better in some regions than in others, and work best at some scales rather than others; the instruments outlined here are scale and context dependent. This simply reflects the diversity of the planet, its human societies and political systems, as well as the tremendous complexity of biological invasion process and its relationship with global biodiversity change.

Finally, there is no doubt that the power to advance the global invasive alien species agenda lies primarily in the hands of governments that lead legal and regulatory initiatives, supported by economic command-and-control instruments, tariffs and penalty systems. Government agencies are, and will likely continue to be, the organizations with the greatest capacity to respond to invasive alien species (Leadley *et al.,* 2014). However, in many cases, especially in countries with developing economies, multilateral and bilateral development aid will play a significant role. The magnitude and intrinsic characteristics of the problem call for an urgent and coordinated diversification of financing options and mechanisms.

6.5.1 Government financing

Government financing continues to play a leading role in invasive management efforts. However, this varies greatly between regions and countries (**Figures 6.4** and **6.5**), partly because of specific national fiscal and regulatory policies and public sector development strategies. In many countries there is considerable government investment in management of biological invasions through sub-national and national support programmes. However, these rarely translate to a multilateral coordinated effort required to adequately address the problem (Tollington *et al.,* 2017). Surveillance and monitoring are also aspects that receive government funding through the efforts of different agencies, but most of these activities have short time horizons, are limited to a few species and lack coordination, which all work to diminish their impact over time (Liebhold *et al.,* 2021).

To achieve adequate management of public funds to respond to invasive species, it is useful to coordinate robust policies at all levels of government in which diverse areas of administration are involved, including but not limited to financial, economic and environmental regulatory bodies, as well as those in charge of international trade and commerce and foreign policy (Tollington *et al.,* 2017, **sections 6.2** and **6.3**). Likewise, it is important to finance educational and outreach strategies to gain public support for the investment of resources into prevention, control and eradication projects (Bertolino & Genovesi, 2003).

Dividing the main sources of tax revenue into four broad categories allows us to understand how each could provide opportunities to respond to invasive alien species at different stages of the biological invasion process:

Direct taxes

The first group is direct taxes paid by households and businesses, which include income taxes, payroll taxes and corporate income taxes, among other taxes (i.e., capital gains and other investment incomes). A portion of direct taxes, which in theory are a reliable source of tax revenue, could be redirected to invasive alien species projects. Specifically, direct taxes are best used to address pre-invasion stages. In pre-invasion stages, biological invasions can be prevented with constant vigilance, including surveillance and monitoring, and therefore sustained funding. Also, investments made in preventing invasions pay dividends, as they eliminate invasions and all the associated costs.

Indirect taxes

The second category comprises indirect taxes, or taxes paid to the government or other public body through a third party, such as a retailer or suppliers. This category includes value added taxes, sales taxes, special taxes on products such as alcohol or tobacco and import duties. Indirect taxes are slightly less dependable than direct taxes because they vary with both household and commercial consumption patterns, as well as the specific tax policies of a given jurisdiction within a nation. Additionally, some subcategories of indirect taxes such as excise taxes can place an unequal burden on taxpayers at different income levels, as the tax per unit of a given good or service will constitute a higher portion of a lower-income taxpayer's income. However, the mandatory nature of this category of tax revenue means that they still are by-and-large a dependable source of tax revenue. Thus, they are appropriate sources of revenue for regular post-invasion control, mitigation and management programmes.

Non-tax revenues

In the third category are non-tax revenues from state-owned enterprises, including revenues from natural resources such as oil and gas. This category could help in research stages, as revenues from such sources already subsidize research in public universities and other institutions in some regions of the globe. Funding for research could be directed towards creating partnerships between public research institutions and natural resource management programmes to increase communication between academia and those responsible for implementing management programmes for biological invasions. This idea is particularly attractive as surveys of invasive alien species programme managers commonly cite a lack of communication with invasive alien species experts as a major barrier to implementing holistic invasive alien species management programmes (Beaury *et al.,* 2020).

External sources

Finally, there is funding from external sources, such as from bilateral or multilateral funding agencies (i.e., World Bank Group: International Bank for Reconstruction and Development (IBRD), International Development Association

(IDA), International Finance Corporation (IFC), Multilateral Investment Guarantee Agency (MIGA), International Centre for Settlement of Investment Disputes (ICSID), Asian Development Bank (ADB), International Monetary Fund (IMF) and International Fund for Agricultural Development (IFAD)), that are also considered public funding when the funds are disseminated through the recipient governments. Governments that depend heavily on funding from these sources are likely to not have other robust sources of tax revenue meant for controlling invasive alien species, and such funds therefore could be used to address the most pertinent areas of management of biological invasions in that region. In regions where there is significant government capacity for managing biological invasions, these funds could be directed specifically towards increasing international coordination of management efforts such as prevention and monitoring. External funding sources could support any action considered as a priority by the government, that requires special support and/or is very costly, such as eradication, or action that depend on international coordination, such as prevention and monitoring.

In summary, the coordinating role and much of the economic drive to address and reduce the risk of invasive alien species currently involves state actors. However, biological invasions are a complex problem with many facets and actors involved (**section 6.2**), so it cannot be thought of as the sole responsibility of governments. While fiscal policies and regulations at the national level have the potential to establish central guidance and coordination mechanisms, it is also important to manage multilateral and bilateral mechanisms, philanthropic support and, above all, to involve the private sector to reinforce government initiatives and address neglected aspects of the problem (Epanchin-Niell, 2017).

6.5.2 Laws, regulations and incentives for the private sector

Three examples of tools available to governments that incentivize the private sector to address invasive alien species prevention and control efforts include: ambient taxes, Pigouvian taxes and compensation, subsidies and fiscal incentives, and promoting the private sector to engage with prevention and control of invasive alien species.

6.5.2.1 Ambient taxes and subsidies

Beyond the more standard sources of tax revenue mentioned above are ambient taxes. Ambient taxes' purpose is to levy taxes on industries responsible for generating non-point sources of pollution, such as carbon emissions or invasive alien species. This type of taxation in the context of invasions, as introduced by Segerson (1988), would incentivize risk reduction by encouraging a shift towards more eco-friendly choices and ensure socially optimal behaviour in both the short and the long run (K. R. Jones & Corona, 2008). Furthermore, these taxes could serve as a cost recuperation strategy (to help pay for invasion impacts) and provide both the financial resources for prevention (including subsidies, surveillance and monitoring) and control strategies. Research has suggested that ambient taxes can be applied to users of ports to incentivize vessels to use proper, resource-appropriate, biosecurity measures (K. R. Jones & Corona, 2008). Effective ambient taxes are tailored to the nature and impacts of invasive alien species from specific ports of entry, which is achieved through greater levels of communication between regulators, researchers and industry stakeholders to reach appropriate tax rates. Furthermore, more research is needed to ensure that these taxes are levied without placing an undue and unequal burden on actors in international trade and into how to properly value the impacts of invasive alien species (Epanchin-Niell, 2017; K. R. Jones & Corona, 2008).

6.5.2.2 Pigouvian taxes

Pigouvian taxes, also known as an "introducers pay" tax, are another market-based approach to addressing invasive alien species control and are a particularly important policy tool when the private control of invasive alien species introductions is insufficient because of negative externalities or impacts from introductions that extend outside the market. Pigouvian taxes aim to tax individuals or companies to interiorize external costs not included in the market price (Sandmo, 2008). The overall aim is to incentive invasion prevention by inducing a cost to the expected damages from an invasive alien species to a level that equals the marginal cost to producers of reducing the risk of invasions. By doing this, producers would interiorize the societal costs not usually included in the market price (i.e., externalities). These taxes are usually perceived as a socially efficient strategy for reducing invasion risk (Epanchin-Niell, 2017), as these taxes force producers to account for the costs accrued to all of society from the risks of possible invasions. However, it is essential to notice that for Pigouvian taxes to yield qualitatively socially desirable behaviours, revenues from these taxes need to be used to offset the impacts caused by the introduced species (Fenichel *et al.,* 2014; Sandmo, 1975). Pigouvian taxes could be considered for imported goods or for dealing with neighbouring or spatial spillover effects (McDermott *et al.,* 2013). In some instances, Pigouvian taxes may even be more efficient than other market-based approaches like ad valorem taxes or tradable permits (McDermott, 2015; Richards *et al.,* 2010). However, like all biological invasions policies, a one-size fits all approach is not recommended and would require significant evaluation and consideration before implementation (Fenichel *et al.,* 2014; Knowler & Barbier, 2005; McAusland & Costello, 2004).

6.5.2.3 Leveraging compensation, subsidies and fiscal incentives and mechanisms

The widely used mitigation hierarchy framework (BBOP, 2012; IFC, 2012) establishes compensation mechanisms in cases of unavoidable and irreparable damage to biodiversity (Arlidge *et al.,* 2018). In instances involving damage by invasive alien species, these measures could be associated with robust and transparent mechanisms for monitoring, regulation and planning, as well as the creation of legislation that provides information on processes and responsibilities. In the case of subsidies, especially in the agricultural sector, these measures could likewise be well legislated and regulated as they can push producers to focus on improving production through reducing the use of unsustainable practices such as monocultures and excessive use of pesticides that can reduce the resilience of ecosystems to possible invasions (OECD, 2017; Robin *et al.,* 2003). It is therefore important to promote interdisciplinary research to develop evaluation mechanisms and indicators that help to anticipate the unexpected effects that these mechanisms may have at different scales and in different agricultural production modalities. In relation to fiscal and economic incentives (Fernandez, 2011), these could not only be oriented to reduce risk, but also to increase the resilience of ecosystems and social groups at high risk of invasions, i.e., the creation of fiscal and economic incentives that promote activities that help prevent, control, manage and eradicate invasions; but also, fiscal and economic incentives that discourage activities that promote the transport, introduction and establishment of invasions; but also, fiscal and economic incentives that discourage activities that promote the transport, introduction and establishment of invasions such as exotic gardens (Dutta *et al.,* 2021) and exotic pet trade (Gippet & Bertelsmeier, 2021).

6.5.3 Multilateral and bilateral financing organizations

Multilateral and bilateral funding organizations already support development and infrastructure programmes around the globe, but their resources and capacity to foster long-term change vary widely with both their organizational priorities and the regions in which they operate (Ray, 2021; **section 6.2**). However, there are opportunities for these organizations to partially redirect their efforts to support the invasive alien species problem without significantly altering their organizational priorities. One potential mechanism would be to update aspects of environmental impact assessments in development and infrastructure projects to place greater emphasis on invasive alien species. Environmental Impact Assessments already gather information on biodiversity (GBIF Secretariat & IAIA, 2020) that, with some effort and coordination, could be oriented to become mandatory, funded mechanisms that provide data for invasive alien species monitoring and prevention systems. Furthermore, environmental auditing has becoming an integral part of infrastructure and other developmental projects (W. Cook *et al.,* 2016). Inclusion of invasive alien species as an indicator in the environmental auditing of such developmental projects may indirectly fund the invasive alien species prevention and control activities. These same mechanisms could also assist in the selection of native species for restoration programmes.

While technical mechanisms are used by multilateral agency groups to incorporate environmental considerations into their investment portfolios, such as Performance Standard 6 (IFC, 2012), these standards do not directly address biological invasions. Though organizations such as the Equator Principles already work with development agencies to explicitly address biological invasions in their environmental considerations, it is also urgent to work with new multilateral and bilateral funding agencies that include large emerging economies countries such as Russia, China, India, Brazil and South Africa. Furthermore, while national governments could require multilateral funding organizations to carry out long-term monitoring of the impacts of development projects, this is often difficult in practice due to the limited capacity of some governments. Therefore, it is important that multilateral funding organizations include in their priorities and budgets adequate resources for sufficient invasive alien species monitoring and evaluation processes.

In order to help to ensure the necessary precautions are taken in the investment portfolios of multilateral organizations, insurance companies and financial institutions could be required to invest in modelling and managing the risks associated with invasive alien species within their various investment activities. Due to the sheer scale of global capital invested in transportation, infrastructure, energy, extractives and other development activities, modelling and management of invasion risk presents an opportunity to prevent negative impacts before they occur. However, for this to be effective it is necessary to develop instruments that interiorize the externalities of societal and environmental impacts of invasions (**section 6.5.2.2**). It is important that these agencies also create funding mechanisms to support research, monitoring and the creation of indicators by sectors such as non-governmental organizations and academia.

Finally, it is important to mention a recent movement to reduce funding for programmes that focus solely on increasing agricultural production and redirect that funding to develop the circular economy (**Glossary**) and incentivize bio-economic considerations and regenerative agriculture activities (Geng *et al.,* 2019). This could become an opportunity to broaden the investment portfolio of multilateral organizations to support countries in their efforts

to establish taxes and fees that benefit invasion prevention and mitigation activities indirectly through strengthening ecosystem resilience to invasive alien species.

6.5.4 Private sector

Investment risk and firm reputation are two important factors driving the private sector (Kocovsky *et al.,* 2018). The private sector could increase its capacity to assess how investment decisions that maximize short-term economic returns also have the potential to trigger biological invasions that can have a devastating effect on its own finances in the medium and long run. As with multi- and bilateral funding organizations, mechanisms could be promoted to help the private sector include the invasion risk component in its economic analysis of different investment options.

To this end, it is important that governments develop and implement policies and legislation at the national and regional level that encourage private firms to include and disclose invasion risk in their reporting frameworks. These analyses can be supported by scientists and contribute to wider research on the development of analytical frameworks and risk indicators. Furthermore, large private sector companies with significant influence and investments in supply chains can help their respective industries to take the necessary considerations to reduce risk through introducing mechanisms that certify products (i.e., green labels), track origin, and generate freely available information to assess, anticipate and monitor the risk of invasion (Kotchen, 2013; Padilla & Williams, 2004). This latter approach could have the extra benefit of raising public awareness of the private sector's role in purposefully or inadvertently creating invasions, thereby making it more attractive for private firms and governments alike to invest in invasive alien species management to protect their public image (Hanley & Roberts, 2019).

Voluntary and self-regulating models, such as corporate social responsibility (CSR) strategies, can also be valuable tools for preventing biological invasions. These strategies imply companies are conscious of the realized and potential impact their activities have on all aspects of society, including economic, social and environmental (Lindgreen & Swaen, 2010). CSR strategies can take multiple forms. These can be voluntary programmes and partnerships to mitigate the environmental impact of industrial plants and production methods (Lindgreen & Swaen, 2010; Rondinelli & Berry, 2000). Alternatively, strategies can include the development of sourcing and marketing initiatives that protect social welfare and commit to environmental benefits (Lindgreen & Swaen, 2010; Roberts, 2003). Wildlife trafficking can be used as an example as to how the private

Box 6 17 Synergies with control mechanisms for illicit wildlife trafficking.

Illegal trafficking of biodiversity has been shown to be one of the main sources of invasive alien species in regions receiving illegally trafficked animals and plants (García-Díaz *et al.,* 2017). Efforts are underway to create new funding mechanisms and strengthen existing ones to combat illegal wildlife trafficking (Wright *et al.,* 2016). One element that can help to deter this illegal activity is the speed of response in relation to species identification (e.g., Kretser *et al.,* 2015). This can be achieved by supporting integration mechanisms of control systems at regional and global levels and increasing the response capabilities of regulatory institutions such as customs and migration agencies at ports of entry and exit (Fajardo del Castillo, 2016).

Previous studies of government response to invasive alien species have identified increased collaboration amongst countries as essential to any future management efforts for biological invasions (Hardisty *et al.,* 2019; Perrings *et al.,* 2010). One option is to develop software intended to foster communication networks (Wallace & Bargeron, 2014; Wise, 2019) and disseminate technical training between and amongst regulatory organizations at the international level (**sections 6.3.1** and **6.6**). However, the process of technification and delivery of capacity-building to regulatory entities and personnel is costly (e.g., Juffe-Bignoli *et al.,* 2016). One way to avoid placing the burden solely on state organizations would be to increase both the criminal and civil liabilities of international freight companies to incentivize those organizations to take the proper precautions to avoid those penalties. This would also help the economic sustainability of expert regulatory entities to maintain the employment of trained technical staff.

Although the private sector has great potential to leverage mechanisms and business practices to help with the issue of invasive alien species, this will not happen without the support of consumers willing to pay the premium for safe products (Akerlof, 1970; Cason & Gangadharan, 2002). Governments could also create mechanisms and conditions for the private sector to feel that it is profitable to invest in invasive alien species prevention, monitoring and the certification of processes and products that directly address the issue of invasive alien species. One way to do this is the promotion of codes of practice for the translocation and exploitation of invasive alien species (**section 6.3.1.3(4)**) and green labelling (**section 6.5.5**). Empowering consumers to exert pressure on large, multilateral corporations to make decisions that help with this problem such as marking products with certifications that consider biological invasion processes can be an acceptable mechanism for the private sector (Kotchen, 2013) that in turn will provide companies with the favourable standing needed to succeed in a competitive global market.

sector is stepping up to help end the illegal commerce of species (e.g., the United States Wildlife Trafficking Alliance) and the tools that can be used to prevent biological invasions **(Box 6.17)**. In this context, codes of practice (**section 6.3.1.3 (4)**) are a viable way by which the pledges made in corporate social responsibility (CSR) strategies can be translated into resources and actions to address the problem of biological invasions.

6.5.5 Role of global supply chains

The impact of global supply chains on the transport and introduction of invasive alien species is undeniable (Hulme *et al.,* 2018; Seebens *et al.,* 2017). The introduction and establishment of invasive alien species are closely related to international trade flows and global trade routes, with international shipping being the main vector for the introduction of invasive alien species (Seebens *et al.,* 2015; Westphal *et al.,* 2008). If the trend of global trade growth continues, it is estimated that the direct annual cost of management of biological invasions in 2050 could reach $36 to $84 billion per year (Deutz *et al.,* 2020).

Incentivizing changes in supply chain management practices offers the opportunity to strengthen the prevention of alien species introductions and therefore decrease the costs associated with controlling and eradicating invasive alien species. One of the key components in driving change in supply chain management practices is elevating the importance of invasive alien species in the minds of end consumers (Hanley & Roberts, 2019). The changes made would encompass corporate commitments to assessing and improving corporate policies, internal standards and funding mechanisms to ensure that supply chains take appropriate precautionary measures, especially in producer countries.

Investments can be made to both improve current practices and elevate the importance of invasive alien species – safe practices in the minds of those responsible for setting corporate strategy (Kocovsky *et al.,* 2018). Importing countries could collaborate with exporting countries to improve sustainable practices that reduce the probability of invasions through their integration into regulations and international trade agreements (**sections 6.3.1.3** and **6.3.2.2**). In this sense, the integration of the component of biological invasions in green labels and certification systems (e.g., Blackman & Rivera, 2010) is especially important because these systems have been shown to be effective in raising public awareness of issues such as deforestation, though labelling by itself does not directly decrease deforestation (van der Ven *et al.,* 2018). Increased public awareness of invasive alien species is a fundamental component in garnering support for new funding mechanisms and policies that have the potential to address invasive alien species more directly. These methods also transfer a large part of the decision to consumers, thereby increasing awareness of the invasive alien species among the public.

6.5.6 Role of philanthropy, non-governmental organizations and academia

While philanthropy represents a significant source of funding for environmental issues such as invasive alien species in some regions, it is almost non-existent in others due to prevailing economic and social systems at the national and subnational level. In some cases, foundations and their philanthropy programmes may be limited by their internally defined priorities, which in many cases are aligned with topics of more widespread public concern (E. R. Larson *et al.,* 2016; Macdonald *et al.,* 2017). This dynamic makes it difficult to develop far-reaching programmes in less visible, but nonetheless important aspects of the invasion process. On the other hand, philanthropic organizations also offer funds to explore innovative invasive alien species programmes (E. R. Larson *et al.,* 2016), but these are quite limited in scope and tend to be used to support specific efforts that align with larger strategic goals of the organizations that receive them. Philanthropic funds are perhaps best used to finance the development of tools and pilot projects that can act as proofs of concept for later implementation by larger, better-funded entities such as governments or financial organizations such as the Global Environment Facility (GEF). In the case of funds that come from corporate social responsibility programmes and multilateral corporations, one option would be to develop metrics and methodological frameworks that the private sector can integrate into their business models to help them report on the impact and investment risk of invasive alien species.

Non-governmental organizations benefit, in large part, from funding sources that have their origins in philanthropy. Although philanthropic organizations have internal mechanisms to define priorities, non-governmental organizations are more transparent in this sense and can channel different philanthropic funds and articulate them to coordinate with programmes pursuing the same objective. Non-governmental organizations, in their constant search for funding to sustain themselves, have the flexibility to change their strategic goals swiftly. This apparent flexibility of the non-governmental organizations can be seen as an asset, as it allows the adaptability of their programmes to be maintained over time; but it also has the potential to drive significant changes in their programmes, and even terminate them altogether.

Finally, there is academia, which also moves with funding from philanthropy, but also receives significant government funding in many parts of the world. The way in which lines

of research are often established early in a researcher's career presents the opportunity to begin cultivating a new generation of invasive alien species specialists in diverse fields. Addressing biological invasions can be achieved through greater coordination between academia and those responsible for implementing invasive alien species best practices; therefore, investments in invasive alien species research can essentially be seen as investments in invasive alien species prevention. One example of this is the Global Register of Introduced and Invasive Species (GRIIS) – a collaborative output demonstrating best practice use of biodiversity informatics to make invasive alien species checklists open (Pagad *et al.,* 2018, 2022). While it is important that foundations provide the funding that supports non-governmental organizations and academia to generate the early ideas that catalyse larger efforts, these efforts could be connected to the private sector, multilateral banks, and the governments to move ideas from pilot projects and proofs of concept to established, long-term programmes. National strategies for invasive alien species are a central mechanism by which this connection can be enabled.

6.5.7 International funding

The mechanisms described here are not the complete solution to financing the global invasive species problem. However, these mechanisms can drive significant change if they are supported, enacted and implemented by governments, multilateral and bilateral organizations, multilateral development banks, philanthropic foundations, non-governmental organizations, academia and the private sector, in a coordinated manner with strong support from informed citizens.

All the options reviewed in the IPBES invasive alien species assessment could benefit from considering different socioeconomic and cultural realities, and presenting common and coordinated strategies that take into account the communities most affected by biological invasions. There are large differences between countries in their capacity to tackle the problem of invasive alien species (Early *et al.,* 2016) and a significant geographic bias in data availability regarding the invasive alien species (**Chapter 2**, **section 2.1.4**; **section 6.6.1(3)**). These limitations have hampered global efforts to reduce the introduction of alien species and prevent their impacts. Flow of financial and other resources from developed countries to developing countries, particularly in Asia and Africa, can improve the understanding of the complex phenomena associated with biological invasions and help developing countries in their efforts to prevention and control of invasive alien species.

Multilateral development banks are in a great position to lead change towards suitable development (Handl, 1998; Trillo, 2021) and achieving the targets set by the Kunming-Montreal Global Biodiversity Framework. At UNFCCC COP 26 in Glasgow, United Kingdom, ten multilateral development banks signed a joint statement on Nature, People and Planet (Messetchkova, 2021), which recognizes that "tackling global poverty, climate change, and the drivers of nature and biodiversity loss are inextricably linked and affirms their commitment to further mainstream nature into their policies, analyses, investments, and operations." under this banner, projects sponsored by these institutions could consider projects aimed at reversing the nature loss caused by invasive alien species.

While it is true that the CBD or the Global Environment Facility could serve to mobilize financial resources, the burden of financing a global strategy need not fall solely on governments and their fiscal policies. It is beneficial to involve all sectors and actors in order to expand the financial resources available. This could also increase the scope of public policies and private sector practices towards sustainability. The need to increase the level of financial resources from all sources and increase the availability of these resources for developing countries is embedded in Target 19 of the Kunming-Montreal Global Biodiversity Framework. Key to this effort will be framing these efforts as medium- and long-term investment opportunities, rather than as necessary sacrifices.

The report on the global biodiversity financing gap estimates that between 722 and 967 billion dollars would be needed to sufficiently confront the crisis, with invasive alien species alone representing between 36 and 84 billion dollars (Deutz *et al.,* 2020). However, these estimates have wide ranges of error due to the limited availability of global biodiversity indicators (Mcowen *et al.,* 2016), as well as many of the data gaps described elsewhere in this assessment. Many uncertainties are related to future investments and the different funding mechanisms that could directly or indirectly support efforts against invasive alien species, but two things are clear: it is possible to reduce the need to invest in the control of and increase investment in the prevention of invasive alien species.

In the era of climate change wherein there is a growing understanding of the interconnectedness of all human activities, both sustainable and unsustainable, it is also paramount not to ignore the ways in which invasive alien species and efforts to combat them might influence and be influenced by other conservation efforts. For example, an important source of funding for biodiversity conservation in general is the carbon credit market, wherein governments voluntarily create offset mechanisms for sustainable forestry practices. Although this funding does not explicitly target biological invasions, establishing transnational safeguards in relation to reforestation and other restoration practices will help to quantify the contribution of carbon credit markets financial mechanisms to preventing invasions.

6.6 INFORMATION OPTIONS

Knowledge of invasive alien species is deeply embedded in the knowledge of the natural world, such as how organisms live, reproduce, disperse and interact. This knowledge is in turn disseminated as information, in different languages, cultures, media and disciplines. Much of it is not permanently preserved, either because it is experience in the minds of practitioners or because it is documented on temporary media. Some information, particularly from scientific publications, is available only from specialized libraries and databases or only at great expense or in a limited number of languages (Nuñez & Amano, 2021). Other knowledge, for example, of pastoralists, is passed down orally between generations and is not necessarily documented. Some knowledge has been rigorously tested using the scientific method, whereas other knowledge is based on observations or on a belief system (Shackleton, Richardson, *et al.,* 2019).

Even if invasive alien species knowledge were all documented and adequately archived there are problems associated with delivering this knowledge to the people who need it. For example, alien species are, by definition, remote from their origins. In the initial stages of an invasion, knowledge of the invader is likely to be better in its native range, or in previously invaded areas, than in the newly invaded range. This disparity includes both access to written knowledge and communication with practitioners who have experience of the invader. Thus, much knowledge that exists on invasive alien species is not adequately findable.

Invasive alien species span the full taxonomic range of species, from large mammals and trees to protozoa and algae (**Chapter 1**, **section 1.3.1**). It is therefore hard to generalize about the information required to support policy on invasive alien species. Knowledge is required both in depth and breadth. That is to say, detailed information on some invasive alien species can provide strong evidence for policy decisions. Yet a broad overview of all alien species would be needed to foresee future threats and to understand the impact of invasive alien species on other species and on people. This makes prioritization of knowledge acquisition difficult, particularly in view of the level of uncertainty in the threats.

Much of the information on invasive alien species is provided by general sources of biodiversity knowledge (Ramírez-Albores *et al.,* 2019). Knowledge sources specific to invasive alien species are also available (Ricciardi *et al.,* 2000), but are restricted to those species known to be alien. In both cases, these sources are often nationally or regionally circumscribed and created for local readers in their own language.

This section first broadly summarizes the knowledge needs identified by previous chapters of this assessment (summarized in **Table 6.10**; **Supplementary material 6.2**), and then discusses key options (**section 6.6.2**) for strengthening the generation and flow of policy and management-relevant invasive alien species information. It also introduces the particular problems faced by Indigenous Peoples and local communities, or isolated communities.

Table 6 10 **Cross-chapter synthesis of gaps in data, information, knowledge and understanding.**

Category	Gap
Gaps on biomes, units of analysis and species groups (section 6.6.1.1)	Incomplete or lack of inventories of invasive alien species in marine, tropical and Arctic ecosystems (**Chapter 2**, **sections 2.5.2.1**, **2.5.2.4**, **2.5.2.5**, **2.5.4**)
	Incomplete or lack of inventories of invasive alien microorganisms and invertebrates (**Chapter 2**, **sections 2.3.1.11**, **2.3.3.3**)
	Lack of understanding of the drivers facilitating biological invasion for some animal groups (notably invertebrates), fungi and microbes (**Chapter 3**, **section 3.6.1**)
	Lack of understanding and synthesis of the impact of invasive alien microbes (**Chapter 4**, **section 4.7.2**)
	Poor understanding of drivers facilitating biological invasions in aquatic and marine systems (**Chapter 3**, **section 3.6.1**)
Regional gaps in data and knowledge (section 6.6.1.1)	Comparatively incomplete inventories of invasive alien species in Africa and Central Asia (**Chapter 2**, **sections 2.4.2.5**, **2.4.5.5**)
	Comparative lack of understanding of the drivers facilitating biological invasions in developing economies (**Chapter 3**, **Box 3.12**)
	Lack of data and knowledge of the drivers facilitating biological invasions in sub-Saharan Africa, tropical Asia and South America (**Chapter 3**, **section 3.6.3**)
	Incomplete data on the impact of invasive alien species across Africa and Central Asia (**Chapter 4**, **section 4.7.2**)

Table 6 10

Category	Gap
Interoperable data for monitoring and research on invasive alien species and on the effects of drivers of biodiversity change **(section 6.6.2)**	Lack of standardization of terminology for invasive alien species monitoring (**Chapter 2**, **section 2.4.4.5**; **Chapter 6**, **sections 6.6.2.3**, **6.6.2.7**)
	The drivers facilitating biological invasions for some animal groups (notably invertebrates) and in fungi and microbes are poorly understood (**Chapter 3**, **section 3.6.1**)
	Lack of information on the role of indirect drivers, especially governance and sociocultural drivers, in affecting biological invasions (**Chapter 3**, **section 3.6.1**, **Box 3.12**)
	Lack of understanding of the net effects of multiple interacting drivers in shaping and promoting biological invasions (**Chapter 3**, **section 3.5**, **Box 3.10**, **section 3.6.1**, **Box 3.13**)
	Lack of knowledge on interactions and feedbacks across drivers in promoting invasions (**Chapter 3**, **section 3.6.3**)
	Lack of integration of data and knowledge sources on impacts across languages (**Chapter 4**, **section 4.7.2**)
	Incomplete data to undertake risk management, cost-effective species-led surveillance and detection of fungi, microbes and marine pests (**Chapter 5**, **Table 5.11**)
	Incomplete data to prioritize biological invasion management under climate, sea- and land-use change (**Chapter 5**, **section 5.6.1.3**)
	Lack of inventories at fine scales and for specific taxon and biome contexts to support decision makers in determining when to implement species-led and site-based management (or both) (**Glossary**; **Chapter 5**, **sections 5.6.2.1**, **5.7**)
	Incomplete data to develop pathway risk assessments and management for different taxonomic groups and biomes (**Chapter 5**, **Table 5.11**, **section 5.6.2.5**)
	Incomplete data and understanding of site-based and ecosystem-based management concepts (**Chapter 5**, **section 5.6.2.1**)
	Incomplete data and understanding of the conditions that facilitate successful integration of policy developments into management plans (**section 6.6.1.4**)
	Lack of indicators[14] of the various dimensions of biological invasion that are policy-relevant, sensitive, reliable, relevant at national and global scales, sustained for medium-to-long-term tracking of progress and part of a responsive policy environment (**section 6.6.3**)
Gaps on how invasive alien species affect Nature's contributions to people **(section 6.6.1.4)**	Incomplete data on impact on nature's contributions to people and good quality of life (**Chapter 4**, **section 4.7.2**)
Management and policy approaches **(section 6.6.1.2)**	Lack of control options for marine invasive alien species and invasive microbial fungal pathogens of plants and animals (**Chapter 5**, **section 5.6.1.1**)
	Lack of agreed-upon methods of supporting management decision-making for invasive alien species with both positive and negative impacts (**Chapter 5**, **section 5.6.1.2**)
	Lack of methods of managing pathways for invasive alien species arriving as contaminating invasive alien species, or through shipping containers, e-commerce (legal/illegal), biofouling or ports, and across land borders and along trade supply chains (**Chapter 5**, **Table 5.11**, **section 5.6.2.4**)
	Lack of methods for adaptive management of invasive alien invertebrates and plants using alternative approaches given the declining number of chemical control options (**Chapter 5**, **section 5.6.2.5**)
	Lack of eradication guidelines and strategies for generalist invasive alien invertebrates, diseases and hard-to-detect freshwater and marine invasive alien species (**Chapter 5**, **section 5.6.2.1**, **Table 5.11**)
	Missing information on the implementation of adaptive-collaborative governance for biological invasions and factors important for the success of this governance strategy (**section 6.4.4.4**)
	Incomplete data on the effectiveness of policies, management strategies and actions related to biological invasions (**section 6.6.3**)
	Lack of scenarios and models of invasive alien species that consider interactions with other drivers of change in nature (**Chapter 2**, **section 2.6.5**; **Chapter 6**, **section 6.6.1.6**)
	Lack of biological invasion research that includes social dimensions to generate socially relevant additional data and knowledge, better inform management and policy and build trust between sectors of society (**sections 6.4**, **6.6.1.4**)

Table 6 10

Category	Gap
Management and policy approaches (section 6.6.1.2)	Lack of multidisciplinary to interdisciplinary research on policy regimes and governance for biological invasions (**sections 6.2.4**, **6.5.1**)
	Lack of tools and frameworks to predict biological invasions (**sections 6.2.1**, **6.6.1.6**, **6.7.2.7**)
Gaps to fill to support the implementation of policy and management (sections 6.6.1.2, 6.6.1.3, 6.6.1.6)	Lack of tools to reduce the barriers to information-sharing within and across countries (**section 6.6.2**)
	Lack of research and data on how best to implement context-specific integrated governance systems to manage biological invasions (**sections 6.6.1.3**, **6.6.1.4**, **6.6.2**)
	Lack of mechanisms that allow effective collaboration among different aspects of the socioecological systems (Figure 6.7, **section 6.7**)
	Policy for new and emerging technological innovations for invasive alien species management to support effective development and implementation and prevent or manage risks (**section 6.3.3**)
	Additional, particularly fine scale, data on how invasive alien species are introduced and spread to support prioritization of introduction pathways and pathway management (**Chapter 2**, **section 2.1.2**; **Chapter 5**, **section 5.6.2**; **Chapter 6**, **section 6.6.1.2**)
	Research and design of economic options, including the tailoring of ambient taxes and analyses and indicators to assist private companies (**section 6.5.1.1**)
Knowledge gaps on invasive alien species of particular relevance to Indigenous Peoples and local communities (section 6.6.1.5)	Lack of information on invasive alien species status and trends on land and water managed by Indigenous Peoples and local communities (**Chapter 2**, **Box 2.6**)
	Lack of clarity on how knowledge, resources and data on invasive alien species should be treated under the Nagoya Protocol (**section 6.6.1.5**)
	Mechanisms for sharing knowledge on invasive alien species with Indigenous Peoples and local communities (**section 6.6.1.5**)
	Understanding the on-the-ground experiences of stakeholders and Indigenous Peoples and local communities and their engagement in invasive species management and governance (**section 6.4.1**) and related network analysis (**section 6.4.4.4**)

14. A headline indicator has been proposed for planning and tracking of progress towards target 6 of the Kunming-Montreal Global Biodiversity Framework, with opportunities to build on existing indicators for biological invasions (**section 6.6.3**).

6.6.1 Invasive alien species information needs

Knowledge gaps result from extreme heterogeneity in the collection and distribution of information and data. Given limited resources so-called gaps could therefore be defined by the questions and the problems that need solutions.

There are many unknowns about the biology of invasive alien species. These are, in part, known limits to what one knows about these species **(Box 6.18)**. Such limits can be described in terms of expressions of uncertainty or as knowledge gaps. The most problematic cases are those species that are entirely unexpected when they start to invade (so-called "unknown-unknowns", or "ignorance" in **Figure 6.18**; Taleb, 2007). Nevertheless, such cases may be novel only to certain sectors and locations. Therefore, inter- and intra- sectoral communication is essential to ensure that the number of surprises (unexpected cases) are minimized. Without such communication it is unrealistic to expect actors in policy and management of biological invasions to be adequately prepared.

Table 6.10 presents a synthesis of knowledge gaps identified in the IPBES invasive alien species assessment. Some of the knowledge gaps are relevant globally, for example the need to increase understanding of the outcomes of multiple interacting indirect and direct drivers of change in nature. Others apply to specific nations or regions and highlight the potential to improve the information and data flow from some regions. There are also gaps in the understanding of the interplay between social, economic and environmental factors that link policy and governance structures. These gaps are best perceived as opportunities to embrace emerging tools and technologies to underpin decision-making and management of biological invasions; indicators and targets on invasive alien species will benefit from improved scenarios and models which are currently limited by the knowledge gaps outlined in this chapter.

Box 6 18 **A case that illustrates the problems of unknowns in knowledge dissemination is the spread of ash dieback disease in Europe.**

This fatal disease of *Fraxinus excelsior* (ash) was detected in Europe the mid-1990s. It was then described as a new species *Chalara fraxinea* (Kowalski, 2006). It subsequently spread across the whole of the European range of *Fraxinus excelsior* (ash). In 2009 ash dieback was identified as being the anamorph of *Hymenoscyphus albidus* that had been described from Europe in 1850 and was apparently native (Kowalski, 2006). However, it was subsequently realized that *Chalara fraxinea* and *Hymenoscyphus albidus* are two cryptic species largely indistinguishable morphologically (Queloz *et al.,* 2011). One causes the pathogenic disease of ash and the other is a harmless saprophyte. This determination led to the establishment of yet another name, *Hymenoscyphus pseudoalbidus*. However, it was later found that *Hymenoscyphus pseudoalbidus* was conspecific with Japanese specimens named *Lambertella albida* (Zhao *et al.,* 2013). Finally, due to the nomenclatural rules of priority and recent changes in the Code of Nomenclature for algae, fungi and plants, the name was changed to *Hymenoscyphus fraxineus* (ash dieback; Baral *et al.,* 2014).

It took twenty years since ash dieback was first discovered in Europe for a stable name for it to be arrived upon, making it possible to connect the species to what is thought to be the native range in Eastern Asia. It is difficult to know how much this confusion over the origin and name of this species contributed to a slow response to the spread of the disease and how much this has obstructed research. This example illustrates the different types of uncertainty associated with biological invasions, in this case both taxonomic uncertainty as well as the need for more research on the distribution and identity of this species group. Furthermore, in the case of ash dieback, once its origins were revealed it allowed information to be brought together from distant sources in time and space.

6.6.1.1 Biodiversity information needs

All seven of the general types of biodiversity knowledge shortfalls (Hortal *et al.,* 2015) are equally relevant to knowledge on invasive alien species and the information needed to resolve this problem, i.e., taxonomy, distribution, populations, evolution, traits and functions, tolerances and ecological interactions. The section below details these types of information needs for policy support on biological invasions and discusses current sources of information and how these are created and disseminated.

(1) Addressing taxonomic biases in research

Taxonomic bias is pervasive in knowledge of biodiversity (Haque *et al.,* 2020; Zamora-Gutierrez *et al.,* 2019), conservation sciences and practices (Creighton & Bennett, 2019) and ecological research (Rosenthal *et al.,* 2017), and such biases have not changed over time (Creighton & Bennett, 2019; Rosenthal *et al.,* 2017; Troudet *et al.,* 2017; **Chapter 2**, **section 2.3.1.11** for an example of information gap on animals). There are probably a number of causes for this. When compared, invasive alien species were more likely to be studied than non-invasive naturalized species (Pyšek *et al.,* 2008), although for many taxonomic groups invasive alien species are also poorly investigated. Other factors that drive taxonomic biases in research include societal preference, research funding, conservation policy (Jarić *et al.,* 2019; Troudet *et al.,* 2017) and probably also research tractability of the species.

Pauchard *et al.* (2011) found that the principal focus of invasive alien species publications in Latin American and Caribbean countries was introduced animals (65 per cent, 119 articles), and often the more tractable or emblematic species. The most studied aquatic alien taxa in South America were fish (26.8 per cent) and molluscs (25.2 per cent), followed by crustaceans, algae, cnidarians, polychaetes and ascidians (Schwindt & Bortolus, 2017).

Taxonomic biases limit the ability to understand the complex processes and interactions that underlie biological invasions. The information obtained from the study of single taxonomic groups is not necessarily transferable to others, for example, due to differences in impacts and dispersal pathways (Jeschke *et al.,* 2012). Therefore, studies targeting few species render generalizations either inaccurate or incomplete (Jeschke *et al.,* 2012). In invasion biology, few studies have examined failure of invasions (Pyšek *et al.,* 2008). However, studying both biological invasion success and failure is important to test invasion hypotheses and understand the overall process of biological invasions (Zenni & Nuñez, 2013; Diez *et al.,* 2009).

Given that taxonomic bias is recognized, any effort to minimize this shortfall will improve information of biological invasions and produce better informed management and policy decisions (Pyšek *et al.,* 2008). Strategies to reduce taxonomic bias include advertising poorly documented and under-studied species among professional and citizen scientists (Troudet *et al.,* 2017), and promoting cross-taxonomic studies that involve a set of invasive alien species that belong to different taxonomic groups (Jeschke *et al.,* 2012).

Tractability of collecting and processing species occurrence data is likely to be a component of these research biases.

Box 6 19 Genetic tools for detection, characterization and traceability of marine and aquatic invasive alien species.

The management of biological invasions can be improved through accurate identification of species to connect with information on their natural history and ecology. Traditionally, these species were identified using methods that require direct observation, or occasionally tracks and signs. In marine and aquatic ecosystems this is particularly problematic due the inaccessibility of working in much of the habitat. Genetic characterization provides an accurate molecular identification of the species and generates information to parameterize population models, genetic relationships, connectivity among populations and the effective population size (Díaz-Ferguson & Moyer, 2014; Díaz-Ferguson & Hunter, 2019; Estoup & Guillemaud, 2010). Molecular genetics can be used to detect founder effects, bottlenecks and hybridization processes that can occur during invasion (Roman & Darling, 2007; Frankham *et al.,* 2010). Genetic approaches can be used to answer questions such as: Are invasive alien species present in an area or region (application challenged in areas where information on native biota is incomplete, e.g., deep sea)? How many organisms are present in an area? Are these organisms able to reproduce? Where are the source populations of these organisms? (A. Barbour *et al.,* 2010; Estoup & Guillemaud, 2010).

For example, identification, genetic characterization and tracking of invasive alien species is only possible due to the development of genetic markers (Pochon *et al.,* 2013). A genetic marker is a deoxyribonucleic acid (DNA) target sequence used for molecular identification of a species or to determine its variability (Díaz-Ferguson, 2012). Since the advent of polymerase chain reaction (PCR; **Glossary**) and quantitative PCR methods several markers have been developed to identify, track and characterize the spatial variation of marine and aquatic populations including invasive alien species (Hulata, 2001; Féral, 2002). More recently the use of mini barcoding and quantitative PCR detection of environmental DNA allows scientists and managers to detect fragments of DNA left behind by species in non-living components of the environment (i.e., soil, sediments and water) without the need to observe or collect the focal species (Díaz-Ferguson & Moyer, 2014). Environmental DNA, although still developing as a technology to narrow uncertainty, has been demonstrated to be efficient at detecting species with a small population size such as invasive alien species in the course of establishment, or imperilled, threatened and endangered species (Jerde *et al.,* 2011). Marine ecosystems are just one of the areas where environmental DNA surveys are likely to radically change the detection and monitoring of invasive species (Chown *et al.,* 2015; Darling *et al.,* 2017; Holman *et al.,* 2019). These methods and others are covered in more depth in **Chapter 5**, **section 5.4.4.2**.

Next generation sequencing (environmental DNA; **Box 6.19**), machine observations (e.g., camera traps and space-based remote sensing) and machine learning will likely make new taxonomic research more feasible.

(2) Overcoming gaps in impact analysis

The number of alien plant species worldwide has been estimated to be in the thousands, but in 2013, robust impact studies were only available for fewer than 200 species (Pyšek *et al.,* 2013; **Chapter 4**). For example, information on the impacts of alien species on biodiversity and on Indigenous Peoples and local communities is a key gap, with particularly acute gaps on impacts across Africa and Central Asia and at the ecosystem level (**Chapter 4**, **sections 4.6.4** and **4.7.2**; **Table 6.1**). Even more substantial information gaps occur in the marine realm where only a small proportion of organisms have been evaluated for their impact in their non-native range, particularly in the deep sea and pelagic open ocean. In a meta-analysis of the impacts of invasive macroalgae data on only 12 species were found, of which only eight had experimental evidence of impact (Maggi *et al.,* 2015). Another review of marine aliens in Europe found only 13 per cent of the reported impacts were supported by experiments and most were only inferred from abundance of the alien and co-occurrence with potentially impacted native species (Katsanevakis *et al.,* 2014). See **Chapter 4**, **section 4.7.2**, for more details on the data and information needs to understand impacts and **Chapter 5**, **section 5.2**, for other use in decision-making.

(3) Reducing geographic bias in research

Invasive alien species are pervasive, but there is disparity of data availability and research efforts across geographic regions. All the studies that examined geographic patterns of data availability (i.e., species occurrence data) and research effort (i.e., publication efforts, ecological study sites) showed geographic biases with a general pattern of high data availability and research efforts in Europe, Australia and North America and low availability in Asia and Africa (Boakes *et al.,* 2010; Yesson *et al.,* 2007; **Chapter 2**, **Figure 2.6**). Such geographic bias is also prevalent among scenarios and modelling studies related to invasive alien species (**Chapter 1**, **section 1.6.7.3**). Geographic bias has already been highlighted in the other chapters (particularly **Chapter 2**, **Figure 2.6** and **section 2.4**; **Chapter 4**, **section 4.7.2**; **Box 6.18**). The recent publication of national checklists of invasive alien species for most of the world's countries helps to overcome this geographic bias, with the focus of these checklists being on invasive alien species with biodiversity impacts and not on all alien species (Pagad *et al.,* 2022).

A systematic review investigated invasive alien species in natural ecosystems (Lowry *et al.,* 2013) and found that such studies were mostly concentrated in North America, Western Europe, Eastern Australia, New Zealand and Hawaii, while there was a dearth of studies in countries located in the tropics, such as in Asia, Africa and Central and South America. This pattern is close to the geographic distribution of sites of overall ecological studies in terrestrial systems (L. J. Martin *et al.,* 2012). Nearly three-quarters of field studies have been done in terrestrial systems, with freshwater and marine ecosystems significantly underrepresented in studies of natural ecosystems (Lowry *et al.,* 2013; **Chapter 2**, **section 2.5.1**). Similarly, countries with a high percentage of IUCN Red Listed vertebrate species that are threatened by invasive alien species (e.g., Mexico, Colombia, Peru, Argentina, Madagascar, India, Indonesia) have a low percentage of publications on biological invasions (Bellard & Jeschke, 2016). In contrast, the countries with a low percentage of invasive alien species-threatened Red Listed species (e.g., Canada, United States, China) have high publication efforts on biological invasions. Alien birds, for example, have been reported in 247 regions across the world, but environmental impact data is available for only 60 regions (24 per cent; T. Evans & Blackburn, 2019).

Taking the example of Latin American and Caribbean countries, the number of articles on invasive alien species over the last 20 years was 344, with an increase after 2003 and a higher percentage between 2003 and 2008 (Pauchard *et al.,* 2011). The country with most articles on invasive alien species was Argentina (105), followed by Brazil (85), Chile (53) and Mexico (41). These four countries contributed 82.5 per cent of all the articles on invasive alien species from Latin American and Caribbean countries. Differences among countries reflect the asymmetry in invasive alien species research among the Latin American and Caribbean countries, but also the effect of country size. Most countries on the continent began publishing on invasive alien species only in the 1990s (Speziale *et al.,* 2012). However, the differences among countries in research effort on alien species does not seem to be just a matter of research budgets, nor differences between developed or developing countries, nor differences due to their higher biodiversity and the interest in protecting it. Although an explanation might be a lower number of invasive alien species in South America, scientific information to properly assess this remains lacking (Speziale *et al.,* 2012).

Generating timely and adequate information across geographic regions is an opportunity for implementing effective management strategies. This is particularly important for the aquatic realm, where eradication and control efforts are viable only at the very initial stages of the invasion process (Lehtiniemi *et al.,* 2012). Lack of information in regions highly vulnerable to invasive alien species may result in a delayed response to invasive alien species at an early stage (Bellard & Jeschke, 2016; **Chapter 5**, **section 5.6.2**). As a consequence of a lack of monitoring, occurrences of invasive alien species can remain unnoticed, thereby reducing the chances of early detection and eradication.

Low research investment and data availability in certain regions, such as parts of Asia and Africa (Bellard & Jeschke, 2016; T. Evans & Blackburn, 2020; Lowry *et al.,* 2013; Pyšek *et al.,* 2008), can mean that these regions are less understood and thus underrepresented when frameworks and theories are developed for biological invasions and their management. Therefore, collaborations between invasion scientists in developed and developing countries, and developing research capacity in less developed countries improves data availability for better understanding of the processes associated with biological invasions (Bellard & Jeschke, 2016). Since geographic biases are also apparent in authorship (corresponding author) of the research articles published in journals like *Biological Invasions*, with disproportionately high submission by authors from North America, Europe and Australasia, such biases can be minimized by encouraging manuscript submissions from countries of other regions (Nuñez *et al.,* 2021). Owing to a lack of study or expertise, discovery of invasive alien species in invaded areas can lag by decades or longer. The numbers of recorded marine invasive alien species are, for example, particularly likely to be underestimated. The size of this gap is difficult to assess, and it varies among different taxa, habitats and regions. Information is most accurate for large, conspicuous, multicellular organisms (Galil *et al.,* 2014; Ojaveer *et al.,* 2015).

(4) Invasive alien species – native and invaded ranges

There are significant data gaps on the spatial delimitation of the edges of species native and invaded ranges, particularly at scales fine enough to inform management decisions (Hardisty *et al.,* 2019; Latombe *et al.,* 2017). Species distribution, specifically native and invaded range, are derived from a wide variety of sources. Indeed, how the definition of what constitutes a native or alien species varies globally depending on the history of human migrations (**Chapter 1**, **Figure 1.1**, **sections 1.3.1** and **1.5.2**; Carthey & Banks, 2012). These differences in definition influence the scope of invasive alien species policy and although the differences can be subtle, they could be considered when directly comparing national alien species inventories (Jackson *et al.,* 2017). Native status is derived from the definition and an evaluation of the available evidence. Such evidence might be direct, such as, from fossil remains, specimens and first-hand accounts. However, native status is often evaluated indirectly from an assessment of the habitat, distribution, evolutionary history and life history of

a species (Essl *et al.,* 2018; Hoagstrom *et al.,* 2009). For certain taxonomic groups evidence is particularly elusive. For example, rare soft-bodied organisms in deep marine habitats are rarely surveyed, and often given the status of "cryptogenic species" (Carlton, 1996; **Glossary**; **Chapter 2** for more examples). Assessments of native status are often made in plant and amimal surveys and are published in taxonomic checklists. In most cases the categorization is uncontroversial. However, in some cases the designation can have political and practical consequences.

6.6.1.2 Uncertainty of information on introduction pathways

Pathways of introduction, particularly in the marine realm, are not always known with high certainty (**Chapter 2**, **section 2.1.2**). Only occasionally are there documented deliberate releases, or clear evidence linking donor and invaded regions, and where species' life history and historical records point to an obvious introduction pathway. In most cases, vectors and pathways are assumed based on the biological and ecological traits of the species, the habitats they occupy in the native and introduced range, and the timing of first record, trade patterns, human use and vector activity (Faulkner *et al.,* 2016; Galil *et al.,* 2014; Hewitt *et al.,* 2004; Wonham & Carlton, 2005). For most species the precise details of their introduction history will not be known with any certainty (Wonham & Carlton, 2005). This might be the reason why only 10 per cent of the studies related to future scenarios and modelling of invasive alien species included pathways (**Chapter 1**, **section 1.6.7.3**). This limits options for governance because without adequate information on introduction pathways, it is difficult to implement policy for biosecurity, prioritize where to invest in interventions to manage biological invasions, or assign responsibility to actors responsible for unwanted introductions (**Chapter 2**, **section 2.1.2** for more information on knowledge and data gaps on introduction pathways and **Chapter 5**, **section 5.3.1** on pathway management strategies).

6.6.1.3 Balancing basic and applied research on biological invasions

There is no clear dividing line between so-called, "pure" research conducted solely for increasing information and applied research that has clear practical applications. Nevertheless, the distinction is made below to help us evaluate the balance of funding and resources devoted to different aspects of science.

In response to the problem, the number of peer-reviewed publications on biological invasions has increased steadily (Vaz *et al.,* 2017). These research publications can be broadly divided into basic research focusing on the process, patterns and impacts of invasive alien species, and applied research, focusing on their management and mitigation. While basic research allows us to understand temporal and spatial patterns of invasive alien species and their underlying mechanisms, applied research builds on the information generated from basic research to develop contextualized management strategies at varying spatial and governance scales.

Basic research dominates peer-reviewed publications on biological invasions (Esler *et al.,* 2010). This disparity may be accounted for by the publication of much applied research in grey literature, such as governmental reports (Lowry *et al.,* 2013). There is also large variation in the use of research methods in basic research. For example, nearly half (46 per cent) of the studies that attempted to understand the fundamental process of biological invasions are field observational studies, while less than one-fifth (18 per cent) were field experimental studies (Lowry *et al.,* 2013).

Similarly, a meta-analysis of biological invasions research from Latin American and Caribbean countries, between 2006 and 2008 found that only 5 per cent of publications focussed on invasive alien species management (Pauchard *et al.,* 2011). Of 185 articles, 57 per cent focused on analysing only one species and 43 per cent on more than one species. Invasion patterns were analysed in 39 per cent of them, invasion mechanisms in 25 per cent, bibliographic invasive alien species reviews comprised 12 per cent, impacts were the focus of 19 per cent, and new invasive alien species were reported in 17 per cent (Pauchard *et al.,* 2011). Basic research focussed on invasive alien species listing, population dynamics, biotic factors that promote invasion and ecological relationships (facilitation, competition and mutualism). The applied research focused on restoration, eradication or control measures (Pauchard *et al.,* 2011 and references therein). Publications on aquatic and marine invasive alien species in South American countries cover six major basic research themes: biology/ecology (58 per cent); invasive alien species new records (20.5 per cent); aquaculture (3 per cent); range expansions; genetics; and general reviews of aquatic species with a remarkably low number (all below 3 per cent), although the proportion of applied research papers is not reported (Schwindt & Bortolus, 2017). Uruguay is an example of a country that has developed both basic and applied research on terrestrial and aquatic non-indigenous and invasive alien species in the last 15 years (Brazeiro *et al.,* 2021; Brugnoli & Laufer, 2018).

Despite the apparent greater investment in basic compared to applied research, knowledge of some basic science questions is still inadequate globally. For example, in an evaluation of country-level checklists of invasive alien species, these were found to suffer from one or more of 10 different error categories, mostly related to poor information or measurement errors (epistemic uncertainties; McGeoch *et al.,* 2012). Important errors include: species misidentified

as alien due to taxonomic uncertainty; failure to recognize invasive alien species as a result of insufficient surveying; overestimation due to the coarse spatial resolution of alien species distribution maps or species listing; delays in the publication of data; poor data management that leads to data being unfindable; incorrect decisions to list a species as "alien" (**Glossary**) due to inadequate and ambiguous information on species' native range; incorrect decision of listing species as "invasive" due to limited information on their population dynamics and impacts, and lack of evidence-based standardized and universal criteria for designating a species as invasive (**Chapter 5**, **section 5.6.2.5**, **Table 5.12**).

While acknowledging that the errors could not be eliminated completely, (McGeoch *et al.,* 2012) suggested some measures to minimize errors associated with country-level checklists, including expanding investment in invasive alien species research and monitoring, improving findability and accessibility of invasive alien species data, improving the speed at which a correction can be applied to a list, and improving transparency and repeatability of invasive alien species listing methods, along with standardized uses of terms and concepts.

Information generated from basic research is translated to management and policy responses through applied research. Poor representation of applied research in peer-reviewed publications (Esler *et al.,* 2010), might have contributed to the continuous increase in the number of alien species across taxonomic groups and biogeographic regions (Seebens *et al.,* 2018). Additional investment of resources for applied research would generate information suitable for managers and policymakers to make decisions.

6.6.1.4 Socioecological research to support policy and management

The prevention and sustainable management of biological invasions depends on an effective integration of environmental, social and economic components in management strategies (D. L. Larson *et al.,* 2011). This implies that an understanding of the socio-economic dimensions of biological invasions is as important as the knowledge held in the fields of biology, taxonomy and other scientific specializations. In spite of the obviously strong human and social dimensions of the invasion process, impacts of invasive alien species and their management (Shackleton, Shackleton, *et al.,* 2019), a 2017 study found that more than 90 per cent of research publications on biological invasions since 1958 were related to ecology and environment, while only 3.2 per cent of the publications primarily addressed socioecological dimensions (Vaz *et al.,* 2017). Similarly, only 3 per cent of 364 research articles related to invasive alien species produced by South Africa's iconic Working for Water Programme between 1995 and 2017 addressed human dimensions associated with invasive alien species (Abrahams *et al.,* 2019).

These scenarios suggest an under-representation of socially relevant research in biological invasion science; expanding it to include social dimensions of invasive alien species through interdisciplinary and transdisciplinary approaches will help to generate socially relevant additional data and information (Abrahams *et al.,* 2019; Esler *et al.,* 2010; Shackleton *et al.,* 2017; **Chapter 4**, **Box 4.5** and **section 4.7.1**). These approaches can not only better inform current management and policy decisions but may also better predict future invasions in an era of global change (Kueffer *et al.,* 2014). Furthermore, a transdisciplinary approach linking ecological and social sciences to generate data and knowledge is also helpful in building trust between communities and resource managers while managing invasive alien species that carry social value (Beever *et al.,* 2019). Ultimately, integrating knowledge systems will be the most fruitful approach to addressing biological invasions, and this includes crosscutting work with the fields of epidemiology, health sciences, economics, political science, sociology, psychology, anthropology, history and others.

6.6.1.5 Knowledge of Indigenous Peoples and local communities[15]

It has long been recognized that Indigenous Peoples and local communities hold unique knowledge on biodiversity. They often inhabit remote, biodiverse landscapes from which they derive diverse resources. Their knowledge may not be documented but may be important to understand ecosystem processes and resource management. Indigenous and local knowledge has been recognized and accepted as relevant to the development and good quality of life of Indigenous Peoples (Sillitoe & Marzano, 2009; Williams & Hardison, 2013). Nevertheless, Indigenous Peoples and local communities have often been excluded from decision-making and would wish to take more control over their cultural and intellectual knowledge (Bolhassan *et al.,* 2014). Historically the power imbalance between the holders and potential users of traditional knowledge have meant that the benefits derived from this knowledge have not been shared equally. Mistrust and misunderstanding has often developed in both directions between academic science and Indigenous Peoples and local communities (Bohensky & Maru, 2011; Mulligan & Stoett, 2000).

Internationally, the need to ensure equitable distribution of the benefits of knowledge and genetic resources has been recognized in the Nagoya Protocol (Buck & Hamilton, 2011). Though the Nagoya Protocol does improve the situation, it

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

is an intergovernmental agreement, and its implementation varies with jurisdiction and does not necessarily include the needs, aspirations and wishes of Indigenous Peoples and local communities. Furthermore, it is far from clear how knowledge, resources and data on invasive alien species themselves should be treated under the Nagoya Protocol because the Protocol is concerned with the benefits of biodiversity and invasive alien species are largely detrimental. The origin of the knowledge and genetic resources can be obscure, and species used by Indigenous Peoples and local communities traditionally are often alien species (e.g., de Almeida *et al.,* 2010). In the case of biological control agents best practices have been drawn up for access and benefit sharing (Mason *et al.,* 2018; D. Smith *et al.,* 2018). However, little consideration of the interests of Indigenous Peoples and local communities is given in these best practices.

Knowledge of invasive alien species by Indigenous Peoples and local communities is vital for not only the community itself, but also for policymakers and practitioners for the purpose of implementing control and management options (Williams & Hardison, 2013). An analysis of the sources of invasive alien species knowledge showed that the majority of Indigenous Peoples and local communities obtain their knowledge from self-learning, observation and experimentation. Another large group mentioned a mix of both contemporary and traditional knowledge sources. A smaller percentage relied on scientific knowledge, showing that Indigenous and local knowledge plays a big role. This also shows how important it is to incorporate both Indigenous and local knowledge and contemporary science while informing policies (Bolhassan *et al.,* 2014).

Communication of information and Indigenous Peoples and local communities[15]

A diverse array of stakeholders and institutions can work together to ensure smooth and effective communication of invasive alien species information. This is not only relevant to Indigenous Peoples and local communities but also to governments, policymakers and to bridge the gap between research and implementation (Barnard & Waage, 2004; Piria *et al.,* 2017). An analysis done on organizations with effective communication on invasive alien species showed that central governments (39 per cent) often have the financial capacity and resources to effectively communicate on invasive alien species. Thanks to their proximity to Indigenous Peoples and local communities, local governments (36 per cent) are also in a position to effectively communicate on invasive alien species. Person-to-person communication (individually; 32 per cent) can be effective as well but often faces geographical limitations and language barriers, which could lead to misinformation (Wald *et al.,* 2019; Zeng *et al.,* 2021). Finally, there are cases of effective communication on invasive alien species through community-led organizations (22 per cent), international and non-governmental organizations (16 per cent).

Knowledge and information needs of Indigenous Peoples and local communities[15]

For an effective and holistic involvement of Indigenous Peoples and local communities and other stakeholders in the control of invasive alien species and management of biological invasions, knowledge dimensions and improvement are vital (IUCN, 2000; Shine, 2003) both in science and practice. Many Indigenous Peoples and local communities (43 per cent of the reviewed case studies) are seeking scientific knowledge, through training, reading and contacting governments and non-governmental organizations, on how to control and manage invasive alien species. Thirty per cent are seeking Indigenous and local knowledge while 17 per cent combined both Indigenous and local knowledge and scientific knowledge. In only 10 per cent of the reviewed case studies, Indigenous Peoples and local communities seek additional knowledge through self-learning. From these findings, it is important for all players to make their data and information available and useful (Groom *et al.,* 2017) to all the stakeholders. The pace towards meaningful participation of Indigenous Peoples and local communities into various sectors of management could be fast-tracked to fill knowledge needs.

Indigenous Peoples and local communities and scientific knowledge[15]

There is significant agreement between Indigenous and local knowledge and science on invasive alien species. There are also some significant divergences, which suggests that continued dialogue will be useful (Byrne *et al.,* 2020; Lopian, 2005) including on species identification, their impacts and pathways of spread. For example, many Indigenous Peoples and local communities recognize invasive plants or animals as foreign in their areas. They were however ready to try different ways to make these useful, for example as food for livestock or food for humans. In other cases, Indigenous Peoples and local communities did not recognize some species as alien, while science would classify them as invasive alien species. This will likely have ramifications for effective communication and control measures, and the involvement of Indigenous Peoples and local communities in decision-making on environmental conservation in different settings. Indigenous Peoples and local communities are using science to supplement and further build on their understandings of invasive alien species. Some report that they supplement the knowledge they acquired from observation and experimentation (self-learning), with science-based training they received.

6.6.1.6 Information needed for invasion scenarios and models[16]

Given the high socioecological relevance of invasive alien species, it is essential to understand how future trends and impacts can be mitigated. There is a strong need to develop scenario narratives, and subsequent quantitative analyses, that assess possible outcomes of various potential trends in alien species distribution, spread and impacts on the environment, economy and society. Here the integration of all information, whether from scientific hypothesis testing or Indigenous and local knowledge, can be vital to developing realistic qualitative baselines to inform subsequent models. Together with robust and relevant targets (e.g., comparable to the 1.5°C target in the climate change discourse), scenarios can underpin decision-making by providing examples of various opportunities and avenues to reach these targets and so inform policy nationally and internationally.

Scenarios and model literature on biological invasions reveals several information needs about policy, future research and action on biological invasions. Most (about 70 per cent) of the studies including both scenarios and models were based on alien species distributions, with only 30 per cent of studies focusing on other biodiversity variables. Species abundance or impacts of invasive alien species and life-history information (e.g., growth, survival) are largely absent from scenarios (19 per cent, 9 per cent and 6 per cent of the publications). The literature is dominated by exploratory scenarios, while target-seeking and policy scenarios are only marginally represented (6 and 7 per cent respectively). Studies using expert-based opinion are practically absent in the available scenarios and models literature (only 1 per cent of papers consider expert opinions). Publications including scenarios and models largely neglect anthropogenic drivers such as demographics, governance, values and technology (each represented in less than 2 per cent of the publications), as well as interactions among different environmental, socio-economic, or cultural drivers. Finally, most studies do not consider policy and management (4 per cent and 21 per cent respectively).

6.6.2 Options for strengthening the generation and flow of information relevant for policy and management

When facing information gaps during the development of governance and policy for biological invasions, or when planning for their management, understanding the type of information gap provides an effective guide for identifying the most appropriate decision-support tools **(Figure 6.18)**. Using a risk assessment framework, it is possible to identify information gaps on the likelihood of invasion outcomes and use this to construct knowledge response options **(Figure 6.18)**. This is also a mechanism for directly connecting specific management scenarios with scientific support tools, including those discussed in the following sections and elsewhere in the assessment (**Chapter 5**, **section 5.6.3.2**).

6.6.2.1 Citizen science as an option for generating information on invasive alien species

Ecological research has long benefited from the voluntary participation of the general public, with participating members often being referred to as citizen scientists (Dickinson *et al.,* 2010; **Chapter 1**, **Box 1.15**; **Chapter 5**, **section 5.4.3.2.a**). In recent decades, citizen science has emerged as an indispensable tool for generating complementary data and information relevant to addressing the problems of invasive alien species and other global environmental changes (Theobald *et al.,* 2015) by tapping the potential of technologies from websites to smartphones for recording biological and environmental data (August *et al.,* 2015). Citizen science approaches can cover larger geographic areas and collect data over a longer period of time than professional scientists alone with the investment of comparable resources (McKinley *et al.,* 2017) and has contributed substantially to monitoring of global biodiversity (Chandler *et al.,* 2017). Some citizen science initiatives have filled geographic gaps for particular taxa (e.g., eBird; Amano *et al.,* 2016; B. L. Sullivan *et al.,* 2014). The options for citizen science to help fill information gaps on invasive alien species are therefore promising (**Chapter 1**, **Box 1.15**).

Commonly recorded parameters in citizen science initiatives are species name, geographic coordinates, photographs, species abundance and habitat description (Johnson *et al.,* 2020). From these primary data, several essential biodiversity variables (EBVs) such as species distribution, population abundance, phenology, demographic traits, migratory behaviours and disturbance regimes have been derived (Chandler *et al.,* 2017). Citizen science has been successfully used in spatio-temporal distribution mapping of invasive alien species (Brown *et al.,* 2018; Johnson *et al.,* 2020; Mannino & Balistreri, 2018; Marchante *et al.,* 2017), prediction of species' suitable climatic niches (Johnson *et al.,* 2020; Tiago *et al.,* 2017), early detection (Giovos *et al.,* 2019; Hiller & Haelewaters, 2019; Palmer *et al.,* 2017; **Box 6.20**), and understanding animal behaviour and plant phenology (Johnson *et al.,* 2020). In addition, citizen science can be helpful in spotting elusive invasive alien species, such as *Python bivittatus* (Burmese python; Falk *et al.,* 2016). It increases public awareness and involvement in the management of invasive alien species while generating scientifically valid data at a very low cost (McKinley *et*

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

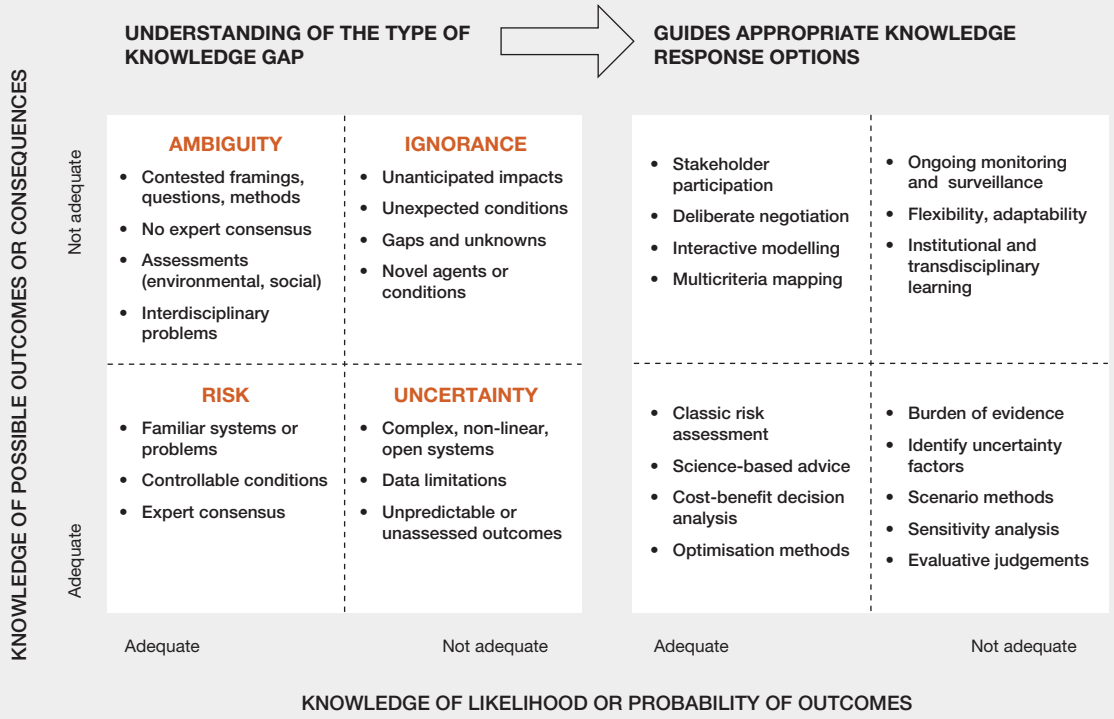


Figure 6 18 **Governing invasive alien species knowledge.**

An understanding of the multiple reasons for invasive alien species knowledge being either incomplete or inadequate (left), leading to the identification of appropriate options for strengthening the evidence base for invasive alien species governance (right; position of quadrants in right panel match those on left). The categories show how traditional, linear invasive alien species risk analysis methods (lower left quadrants in each panel) are on their own inadequate tools for governing the knowledge on invasive alien species needed to inform policy. For example, "Assessments" outline the broad suite of policy questions relevant to biological invasion, make it clear that no single solution is adequate and that options can be context dependent (Stirling, 2010). Adapted from Linke *et al.* (2016) https://doi.org/10.1007/978-3-319-27006-7_8, under license CC BY 4.0 and Stirling (2010) https://doi.org/10.1038/4681029a, under copyright 2010, Springer Nature Limited.

al., 2017; Palmer *et al.,* 2017). For recording species' distribution data, citizen science can be more cost-effective, nearly eight times less in case of Mosquito Alert, than the traditional expert-driven approach for data of comparable quality (Palmer *et al.,* 2017). Citizen science data can contribute substantially to existing species information data (e.g., early detection, species distribution range size, regional species pool) collected by professional scientists (Crall *et al.,* 2015; Palmer *et al.,* 2017; Soroye *et al.,* 2018).

Nevertheless, there are limitations to the use of citizen science, as shown by Pocock *et al.* (2019). There are large taxonomic and geographic gaps in data. For example, eight of the 26 citizen science initiatives with a web/mobile app evaluated focused on single (e.g., Mosquito Alert) or several priority invasive alien species (e.g., That's Invasive!, iMapInvasives) while the remaining initiatives (e.g., iNaturalist, eBird) include both native and alien species (Johnson *et al.,* 2020). Similarly, the number of invasive alien species focused citizen science initiatives leading to scientific publication was higher in Western Europe (11) and North America (10), and there was no such initiative in Asia (Johnson *et al.,* 2020). This is expected because 42 per cent and 32 per cent of all citizen science programme activities (N = 420) linked to biodiversity monitoring have been operating in North America and Europe, respectively (Chandler *et al.,* 2017). Expanding taxonomic and geographic coverage of citizen science initiatives increases the scientific values of the data generated. Adaptive sampling, whereby volunteers are guided to make observations in locations which will optimally improve species maps, has the potential to improve the effectiveness of citizen science for early warning of invasive alien species.

Citizen science programmes for invasive alien species detection and surveillance have recently expanded to marine systems (Delaney *et al.,* 2008; Thiel *et al.,* 2014), with active involvement of fishers, divers and the public at large. The contribution of citizen science is expected to expand over time, helping to address the limited funding and spatial/temporal coverage available with current programmes (Pocock *et al.,* 2018, 2019). However, some constraints could be considered in programme design and

expectations, including selecting large-bodied, conspicuous taxa with easy-to-recognize diagnostic characteristics. In the future, genetic tools may be also adopted by citizen science programmes to enhance the potential taxonomic scope and for validation purposes (Ojaveer *et al.,* 2018).

Data from citizen science can contribute significantly towards a better understanding of biological invasions and other global environmental changes, provided that these data are adequately used in peer-reviewed publications (Theobald *et al.,* 2015). Some scientists are reluctant to use citizen science data, though relevant to their objectives, due to uncertainties related to data collection methods and data attributes (Burgess *et al.,* 2017). Accompanying citizen science data with metadata describing data quality, availability, conservation issues being addressed, study taxon and system, spatial and temporal scales of measurement, sampling intervals and data standardization protocols improves transparency and encourages scientists to use citizen science data (Burgess *et al.,* 2017).

In spite of the voluntary contribution of participants, citizen science data are not always openly shared (Groom *et al.,* 2017). In a recent study, nearly half (54 per cent) of the 26 invasive alien species-relevant citizen science initiatives evaluated did not share data with other similar initiatives or other biodiversity data-sharing facilities (Johnson *et al.,* 2020). Sharing data among other citizen science initiatives working in similar geographic regions/scales and taxa, and consolidating results in shared databases, would increase use values of citizen science data in scientific research, and policy and management decisions (Johnson *et al.,* 2020).

6.6.2.2 Professional networks and platforms for coordination and information exchange

It is important to understand patterns and processes of biological invasions at varying spatial scales for effective management. Several information systems and approaches are available at national, regional, continental and global

Box 6 20 Citizen science for early detection and rapid response.

After prevention, early detection and rapid response (EDRR) is the most effective and least costly way to manage invasions. The main hitch is the inability to generate enough resources to support a sufficiently large professional staff to survey with adequate frequency the vast amount of land and water that can house recently arrived invaders. Yet a well-informed, educated public can vastly increase the number of "eyes" on the lookout for incipient invasions; and individual citizens in the course of other activities have spotted hugely damaging invasive alien species in time to permit complete eradication before the species had spread widely. Such was the case of an individual sawing off an overhanging tree branch in Chicago and noting signs of *Anoplophora glabripennis* (Asian longhorned beetle; Kridel, 2008; Manier & Martin, 1998) and a recreational diver finding the famed *Caulerpa taxifolia* (killer algae) in a California lagoon (Muñoz, 2016).

Rather than simply relying on publicity about invasions and the hope that an alert citizen will happen to observe a recently arrived invader and know how to report it, several organizations have trained citizen volunteers and organized their search activities to maximize the probability of detecting recently arrived and potentially invasive plants. In the Australian state of Victoria, the Victorian Weed Spotters program, initiated in 2008, trains citizens to find and report state-prohibited weeds, and these reports are viewed as valuable components of the state programme to prevent weed establishment (Munakamwe *et al.,* 2018). In 2012 in the state of Washington, United States, the Pacific Northwest Invasive Plant Council organized an EDDR Citizen Science Invasive Plant Program to train volunteers to support county, state and federal management agencies to locate and eradicate invasive plants, a programme that has now expanded to the state of Oregon (PNW-IPC, 2018). Perhaps the most expansive such programme was organized by the Invasive Plants Atlas of New England (IPANE) in 2001 to integrate independent efforts of the six New England States. The programme, associated with an atlas of invasive plants in this region, trains volunteers both to find and to identify invasive plants, assigning particular monitoring routes. The programme is associated with EDDMapS (EDDMapS, 2019), a system of reporting and mapping alien species in the United States. However, the death in 2010 of the key innovator of the IPANE programme has led to a dearth of funds for training volunteers, and the programme itself has lapsed.

Aceves-Bueno *et al.* (2015) examined 83 citizen science programmes that entailed monitoring, of which five (including IPANE) targeted invasive alien species. In addition to substantial contributions to various resource management activities (including managing invasions), this study pointed to the important benefit of engaging a wide swathe of the public in recognizing and dealing with environmental issues, whether or not they associate themselves with formal programmes such as those described above. An important consideration, however, is the accuracy of monitoring records reported by citizen scientists, as noted by Crall *et al.* (2011) for an organized effort to monitor for invasive plants. This consideration supports the importance of substantial training for citizen volunteers, which bears a non-negligible cost. Another important step is to implement validations of citizen science invasive alien species data by experts (e.g., taxonomists) or through automated machine learning approaches (e.g., computer vision) or even by Artificial Intelligence.

scales to support information flow across jurisdictions (Katsanevakis & Roy, 2015; Mulligan & Stoett, 2000). Global analyses, for example, are essential for informing international policy to address the problems of invasive alien species, including those focussed on particular habitats and ecosystems. Collecting empirical data from diverse geographic areas will be improved by collaboration across strong networks of researchers, managers, practitioners and informaticians (Packer *et al.,* 2017). Previous and current examples of such collaborative networks include the Mountain Invasive Research Network (MIREN); European Information and Research Network on Aquatic Invasive Species (ERNAIS); Global Invader Impact Network (GIIN); Global Invasions Research Coordination Network; *Phragmites* Network (PhragNet); the Southern Hemisphere Network on Conifer Invasions (Packer *et al.,* 2017) and the Pacific Invasives Partnership, that is part of the Secretariat of the Pacific Regional Environment Programme (SPREP; for additional examples see **Supplementary material 6.3**).

International networks

GRIIS is supported by a broad collaboration of agencies and country experts. GRIIS provides open country checklists as well as a collated compendium of invasive alien species across countries (Pagad *et al.,* 2018, 2022). GRIIS data are openly available through an online repository, through the Global Biodiversity Information Facility (GBIF), and *via* country pages of the CBD Access and Benefit-sharing Clearing-House. GRIIS is founded on a transparent set of methods and biodiversity information standards (**section 6.6**) and provides both a baseline information source and mechanism for supporting an international information platform for invasive alien species (Pagad *et al.,* 2018, 2022).

At its 15th meeting, the CBD COP called for multiple international networks to continue supporting the implementation and monitoring of the Kunming-Montreal Global Biodiversity Framework (including Target 6 for invasive alien species), most notably the Statistical Commission, the Group on Earth Observations Biodiversity Observation Network (GEO BON), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem and Services (IPBES) and the Biodiversity Indicators Partnership (BIP) (CBD, 2022b), as well as the ISSG, GBIF and CABI (CBD, 2022c).

Previous and current international networks on invasive alien species that promote data sharing and collaboration include the ISSG, The Inter-American Biodiversity Information Network (IABIN), the Asia-Pacific Forest Invasive Species Network (APFISN), the European Network on Invasive Alien Species (NOBANIS) and CABI (which produces the Invasive Species Compendium). The European Alien Species Information Network (EASIN) provides opportunities for pan-European cooperation for sharing of information and assists implementation of European policies on biological invasions (Katsanevakis *et al.,* 2013). Also, a European Co-operation in Science and Technology (COST) action was launched to establish an alien species and citizen science network to develop and support citizen science initiatives (Roy *et al.,* 2018).

National and subnational networks

Examples of national or subnational initiatives, in this case from Europe are: a) a French working group on biological invasions in aquatic environments which aims at promoting expert knowledge, providing access to scientific information and guidance to decision-making for capacity-building to manage biological invasions (Sarat *et al.,* 2017) and b) a national code of conduct to prevent the introduction and spread of aquatic invasive plant species in the Netherlands (Verbrugge *et al.,* 2014).

Aquatic networks and information systems

An online information system on aquatic non-indigenous species and cryptogenic species (AquaNIS),[17] or species that might be considered to be invasive alien species, stores and disseminates information on invasive alien species introduction histories, recipient regions, taxonomy, biological traits, impacts and other relevant documented data (Olenin *et al.,* 2014). AquaNIS is being routinely updated by the supporting network (including by the members of the Working Group on Introductions and Transfers of Marine Organisms of the International Council for the Exploration of the Sea, ICES WGITMO) and contains information from various parts of the world.

Standard protocols

The Mountain Invasive Research Network was established in July 2005 during an international workshop on plant invasions into mountain regions in order to generate and share information of biological invasions in mountain regions of the world (Dietz *et al.,* 2006). The network has developed standardized protocols for data collection. Participating researchers use the same protocol while collecting data in mountain regions around the world. Use of empirical data collected from different parts of the mountain regions through this network has provided broad understanding of plant invasion patterns in mountain regions (e.g., J. M. Alexander *et al.,* 2011; Liedtke *et al.,* 2020; Seipel *et al.,* 2012). Similarly, the Global Invader Impact Network (GIIN) has developed a standard protocol for quantifying baseline ecological impacts (Barney *et al.,* 2015) and the methods have been already used to study impacts of species like *Impatiens glandulifera* (Himalayan balsam, Čuda *et al.,* 2017) and *Microstegium vimineum* (Nepalese browntop; Tekiela &

17. http://www.corpi.ku.lt/databases/index.php/aquanis

Barney, 2017). Some networks have become inactive and no longer collect data or update online resources.

Supporting active networks and platforms, re-activating previously established networks and developing new networks focusing on relatively less studied (e.g., wetlands) and difficult to quantify (e.g., marine) ecosystems creates opportunities for collecting and collating data using standardized protocols to improve knowledge of biological invasions.

6.6.2.3 Integration of information

Invasive alien species data in a biodiversity data context

The concept of essential biodiversity variables (EBVs) has been proposed to harmonize and unify efforts towards being able to provide regular, reliable and up-to-date information on key measurements of biodiversity change (Pereira *et al.,* 2013). Key elements of the EBV approach include aggregating and integrating biodiversity information (including on genes, species populations, traits, communities and ecosystems) across multiple sources, advancing the biodiversity information standards needed to achieve this, and state of the art modelling to deal with data gaps and provide estimates of uncertainty around projections. Generating such data products at a global scale has been challenged by the slow mobilization of data, inconsistent use of standards, a lack of standards and unevenness of data availability; problems which are now being overcome (Jetz *et al.,* 2019; Kissling *et al.,* 2015). Indeed, one of the goals of defining essential biodiversity variables (EBVs) is intended to be supporting the collections of up to date and higher quality raw observations of biodiversity **(Box 6.21)**. To create such essential biodiversity variables (EBVs) and tackle the underlying difficulties, automated workflows could make it feasible to repeat the process regularly and in a timely way (Best *et al.,* 2007; Kissling *et al.,* 2018). Workflows would output information that can be easily digested by policymakers and other stakeholders, who do not necessarily understand all the details of the workflow, but who need an appreciation of the data's limitations (Jetz *et al.,* 2019).

Integration of invasive alien species data through essential biodiversity variables

Three essential biodiversity variables (EBVs) have been identified as critical for measuring change in invasive alien species and underpinning invasive alien species indicators: alien species occurrence, the status of an individual or species as native or alien and invasive alien species impact (Latombe *et al.,* 2017; McGeoch & Jetz, 2019). To generate EBVs adaptable automated workflows are envisaged that can harvest raw data, aggregate them and standardize them to output the final EBVs product (Hardisty *et al.,* 2019).

Automated workflows for invasive alien species data integration and analysis have the advantage over bespoke programmes and semi-automated processes in that

Box 6 21 **Institutionalizing invasive alien species monitoring: a case study from India.**

Purpose

An example of how invasive alien species monitoring can be mainstreamed into government mandates is that of India's *National Tiger Estimation Program*. The government of India uses this program to estimate tiger populations at a national scale every fourth year and the program has been running since 2006. This monitoring not only produces an account of tiger numbers at a national scale, but also uses this charismatic species to garner resources and public support for protecting natural systems and their functions (Jhala *et al.,* 2021).

Approach

The National Tiger Estimation Program sampling protocol is developed to collect information on the distribution of important carnivore and herbivore animals, as well as their habitat quality. The protocol for assessing habitat quality is used for collecting information on invasive plants and native weeds. The primary objective of monitoring is tiger conservation, whereas weed monitoring is a conservation objective in its own right. The case demonstrates how, with appropriately well-integrated strategy and planning at national and sub-national scales, multiple biodiversity monitoring objectives can be simultaneously met – including invasion monitoring.

India has a large human resource with a mandate to monitor and protect forest ecosystems **(Figure 6.19)**. The National Tiger Estimation Program uses this trained capacity in collaboration with scientific institutions to sample forested areas at a 10×10 km resolution. Within every cell of 100 km^2, 20-40 plots of 10-30 m diameter are sampled to record the abundance of available plants. Since 2018, the data are recorded through an open-access mobile app (MSTrIPES) that stores this information in native language, along with geotagged photographs of the plot. These data are transferred to a cloud server, where existing algorithms compute trends in invasion of different species at a desired scale (e.g., Mungi *et al.,* 2020). The system can be further used to relate invasive alien species presence to herbivore and carnivore distribution. These analyses are reported back to the data collectors and managers, who can use them to prioritize evidence-based invasive alien species management and research (e.g., Mungi *et al.,* 2021).

Box 6 21

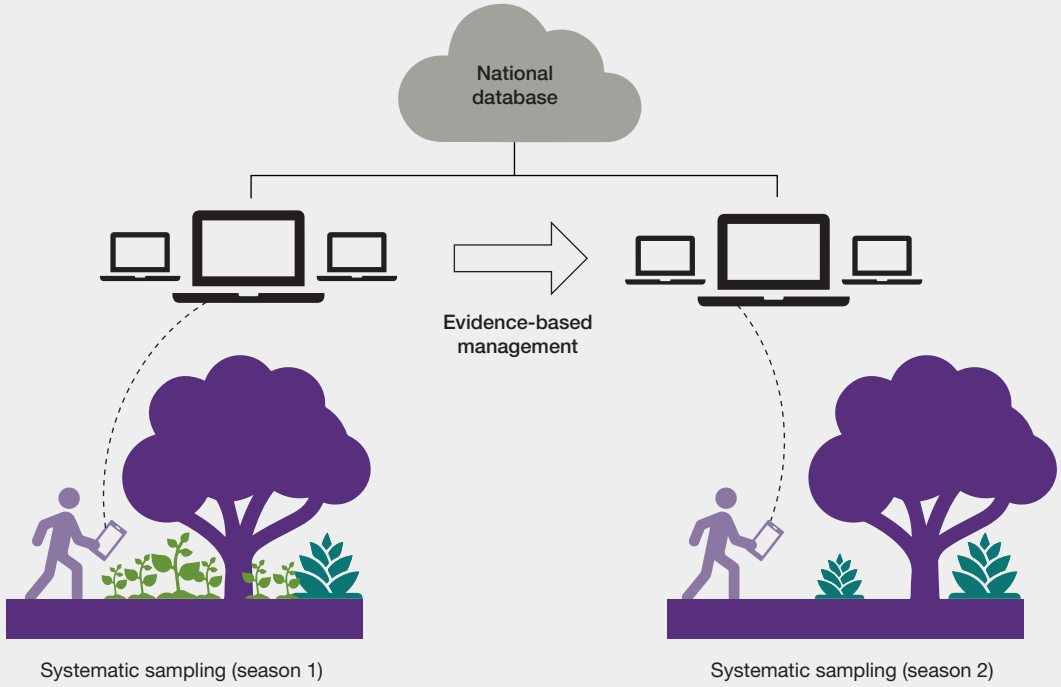


Figure 6 19 **Systematic monitoring scheme for invasive plants in Indian forests.**

The research team records abundance of invasive plants in sampling plots of every 100 km^2 cell across tropical India. The information is recorded on mobile apps that transfer field data to a regional workstation and cloud server, where spatial analyses are done to map and prioritize invasive plant management. The process is repeated at a national scale every four years. Recent monitoring in 2018 was the most extensive with more than 150,000 habitat plots sampled, revealing that 76 per cent of Indian forests invaded by different invasive plants at an alarming rate.

Combining monitoring and management

Importantly, the present monitoring protocol not only generates data, but it is also proactive. The sampling teams are equally involved in habitat management. In addition to evidence-based science, the present sampling protocol convinced the stakeholders to monitor invasive plants for conserving forest habitat that will help increase herbivore densities. This in turn will ensure sustenance of top predators, including the tiger. Serving as a unique platform to host scientific and management priorities, the present monitoring protocol is mandated by government agencies for continual application in India. This case can serve as an exemple for other countries who wish to mainstream and institutionalize invasive alien species monitoring with the limited resources availed for conserving iconic species.

they are flexible, repeatable, easily shared and can be repurposed (e.g., Seebens *et al.,* 2020; Reyserhove *et al.,* 2020). They can also take advantage of code written by many people and use shared resources. Workflows fit well into the ethos of open source and open science practice (Goble *et al.,* 2010). Although they are not yet widely used for invasive alien species data analysis, examples exist (De Giovanni *et al.,* 2016; Seebens *et al.,* 2020; **Box 6.21**).

A trial was conducted on the species distributions for three widespread invasive alien species to generate data ready to be used in essential biodiversity variables (EBVs; Hardisty *et al.,* 2019). This work identified some areas where research investment in data information systems for invasive alien species is needed. The workflow was based on the large open infrastructures GBIF and Atlas of Living Australia. They encountered several difficulties in fully automating their workflow, which served the purpose of identifying where further advances are needed in data integration methods and standards. Even though these infrastructures are based on the same standards, they encountered many inconsistencies between datasets, and required considerable manual expert input to complete the workflow. At a continental scale, a completely automated workflow has been created in the programming language R, specifically for generating indicators and models of invasive alien species distributions

(Oldoni *et al.,* 2020). Ultimately, it is conceivable that automated workflows will be built to generate essential biodiversity variables (EBVs) at a global scale; however, research and development are still needed to resolve data consistency problems and to develop analytic models.

6.6.2.4 Open science – open data for invasive alien species

The Open Knowledge Foundation defines "Open" as "… anyone can freely access, use, modify and share for any purpose (subject, at most, to requirements that preserve provenance and openness)" (Open Knowledge Foundation, 2021). The open data movement has been an important driving force increasing access to data (Molloy, 2011), and can do the same for invasive alien species data. This development has been motivated by the desire to improve transparency and reproducibility of science, but it also aims to improve the efficiency of science by avoiding unnecessary duplication of effort. The push toward open data is energized by the need for interoperability, particularly in complex, data-intensive science, such as invasion biology (Reichman *et al.,* 2011). Several widely supported declarations have been penned to encourage open data sharing in biology and science in general (Budapest Open Access Initiative, 2012; pro-iBiosphere Consortium, 2014). Indeed, there have been specific calls for data on invasive alien species, in particular, to be open (Groom *et al.,* 2015, 2017).

Related, but not synonymous with Open Data are the Findable, Accessible, Interoperable and Reusable (FAIR) data principles (Wilkinson *et al.,* 2016). Openness does facilitate findability, accessibility and reusability, which is why FAIR data often go hand-in-hand with open data. One motivation for promoting FAIR data is that research data are easily lost once the research they support has been published (Vines *et al.,* 2014). Without FAIR open data on invasive alien species, it is difficult to provide informed, integrated policy support nationally or globally.

Many online resources are available for sharing information about invasive alien species (**Chapter 5**, **Table 5.4** for examples). These resources vary considerably in how well they conform to the FAIR data principles, and how readily complementary information can be integrated from multiple sources to answer questions about biological invasions (**section 6.6.2.3**). There is considerable room for improvement and innovation to make resources for biological invasions more findable, accessible, interoperable and reusable.

6.6.2.5 CARE principles for Indigenous data governance

In analogy to the FAIR Data Principles, and complementary to them, are the Collective Benefit, Authority to Control, Responsibility and Ethics (CARE) Principles for Indigenous Data Governance[18] (RDA, 2019). These Principles try to address some of the historical and ongoing imbalances in governance of data concerning Indigenous Peoples. The letters of the acronym refer to Collective Benefit, Authority to Control, Responsibility and Ethics. The collective benefit, authority to control, responsibility and ethics (CARE) principles are not specific to data types and make no mention of particular issues related to data on biodiversity and invasive alien species. However, they are mentioned here because they are important guidelines concerning Indigenous and local knowledge and useful guidelines for the ethical management of any data needed on biological invasions.

6.6.2.6 Open access publication

Closed access to invasive alien species research has been recognized as a hindrance to conservation, wildlife management and policy on invasive alien species (Groom *et al.,* 2015; Jeschke *et al.,* 2019). This has led to the establishment of an international association, International Association for Open Knowledge on Invasive Alien Species (INVASIVESNET), to support the open dissemination of information on invasive alien species (Lucy *et al.,* 2016). Several open access academic journals have been established specifically on the subject of invasive alien species, their biology and management. For example, *Management of Biological Invasions*, *Aquatic Invasions* and *BioInvasions Records* are published by the Regional Euro-Asian Biological Invasions Centre (REABIC) and Neobiota is published by Pensoft. However, these discipline-specific journals publish only a small fraction of the academic research on invasive alien species. For scholarly literature in general, about 28 per cent is open access, but that percentage is increasing (Piwowar *et al.,* 2018). There is also clear evidence for an Open Access "advantage" in terms of citation (Eysenbach, 2006; Niyazov *et al.,* 2016; Piwowar *et al.,* 2018). However, this advantage may come at the expense of lower discoverability and access to other valuable research because closed access publications may be inaccessible to many researchers, particularly in low-income countries.

Information on invasive alien species is published in a wide variety of media and outlets, from journals and pamphlets to books. Much of this body of knowledge is not in publications dedicated to invasive alien species specifically but embedded within literature on biodiversity or ecology in general. Rapid access to scientific publications is essential to inform practitioners about a species and even to identify it in the first place. Nevertheless, those publications that are confined to paper are available for sale only for a short time after publication and then are available only in specialist or local libraries. Access to digital repositories, such as Zenodo, is providing a place where grey literature

18. https://www.gida-global.org/care

can be deposited for long-term preservation and findability. However, there also needs to be a change to the publishing culture so that all publishers consider the long-term archival of their work.

Researchers use indexes, such as Google Scholar, to discover potentially useful publications, though the accessibility of those publications varies. Gold Open Access publications are completely accessible to users and their licensing usually makes them reusable. However, at the other extreme are closed access publications that require large sums to access. Researchers are often adept at avoiding such costs and piracy of closed access publications is rife (Timus & Babutsidze, 2016). Even academics with legitimate access to scientific publications appear to find it easier to access papers illegitimately (Bohannon, 2016). This shows a demand for this scientific knowledge globally and a problem with the marketplace for academic knowledge (Björk, 2017), with particularly serious implications for research areas where environmental, social and economic costs of delays in the dissemination of information are serious, such as invasion biology.

6.6.2.7 Data standards for invasive alien species data

Global standards for invasive alien species information facilitate rapid, unambiguous communication and enable the delivery of indicators of invasions, regional comparisons, which in turn feed into policy support tools. Standards for data exchange of taxon observations have been around for a number of years and Darwin Core is predominant among them. Darwin Core has been adopted by GBIF (Canhos *et al.,* 2004). Until recently Darwin Core lacked some important features to make it useful for communicating about invasive alien species. However, recently proposals have been made to include the degree of establishment and introduction pathway within Darwin Core, together with controlled vocabularies for those terms. These changes have now been implemented by GBIF and it now requires data publishers to embrace these terms and use them (Groom *et al.,* 2019).

Few other official standards exist for specific data related to invasive alien species. However, several quasi standards exist under the umbrella term “framework”. For example, Hulme (2009) published a framework for introduction pathways. The intention was to have a globally applicable pathway classification that could be used for all invasive alien species, whatever their natural habitat. This was to address a need to monitor pathways of introduction and to communicate pathway information in a more comparable way. A guide has been written to help users of the framework to interpret different pathway categories and improve consistency (IUCN, 2017). The CBD (2014a, 2014b) has developed a pathways framework, as has the ISSG (Pagad *et al.,* 2015). This is tied to the Aichi Biodiversity Target of identifying, prioritizing and managing pathways of invasive alien species. Armed with such information it becomes easy to provide the evidence to support policy on pathways (**Chapter 5**, **section 5.3.1**).

Nevertheless, the framework is still only a standard suitable for human interpretation and unsuitable for machine interoperability. Only by formalizing the framework as a data standard can the latter be achieved. The Invasive Organism Information Task Group of the Biodiversity Information Standards organization has proposed changes to Darwin Core to incorporate pathway vocabulary, adopted by the CBD (Groom *et al.,* 2019). These recommendations have been ratified by the Biodiversity Information Standards organization who manage Darwin Core but may take a number of years to be adopted by the wide range of stakeholders who gather, manage and use these data. Progress towards machine readable standard data will make the vision of creating rapid and reliable workflows towards policy-relevant indicators feasible (McQuilton *et al.,* 2016; Rocca-Serra *et al.,* 2016).

6.6.3 Tracking and reporting on policy and management effectiveness: indicators, metrics and datasets to support policy

Reporting on the effectiveness of policy in generating progress towards targets and goals for invasive alien species takes place at multiple jurisdictional levels – from global to subnational. Regardless of the level at which evaluation of policy effectiveness is needed, such evaluation relies on relevant and adequate data and analysis. The information needed for reporting on invasive alien species includes (i) the identity and spread of invasive alien species, including the pathways *via* which this occurs, (ii) the type and severity of impacts incurred by particular invasive alien species, (iii) societal values impacted, including for example, biodiversity, agricultural and human and animal health and (iv) data on management interventions (left of **Figure 6.20**; **Box 6.22**).

A key instrument to progressing efforts to deal with invasive alien species is the use of a range of indicators of status and trends in invasive alien species. These indicators are designed to be used for reporting on policy goals and targets at national and global scales, including the Kunming-Montreal Global Biodiversity Framework (Target 6 for invasive alien species) and the Sustainable Development Goals. Importantly, such indicators, supported by relevant metrics and data, have a longevity beyond medium term reporting cycles so that progress can be tracked consistently over the long-term. To date, invasion indicators that are global in scope have been used across five Global Biodiversity Outlook Reports (SCBD 2001-2020), and to

Box 6 22 Sustainable delivery of information on invasive alien species for reporting on policy and management effectiveness.

Figure 6.20 below shows a proposed framework for closely linking invasion targets with the data and tools needed to measure and make progress to achieving them (McGeoch & Jetz, 2019). Combined in digital, modular platforms with custom tools and interfaces the framework enables both evaluation of global progress and decision-support for local actions.

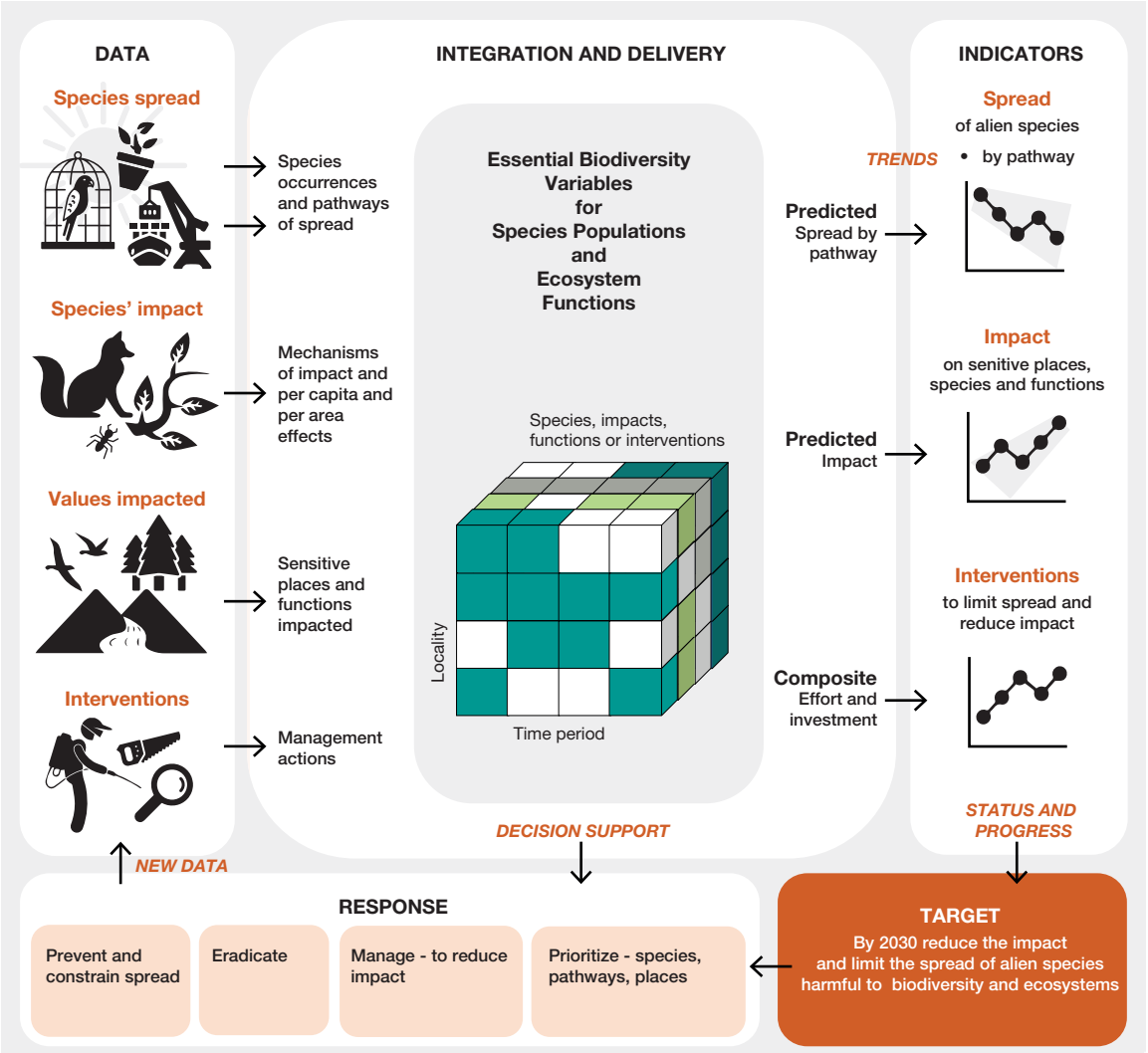


Figure 6 20 **Proposed framework for closely linking invasions targets with the data and tools needed to measure and respond to them.**

The target (lower right) frames and guides data generation, integration and delivery *via* modelled decision support products and indicators, to target responses for more effective intervention and a next generation of improved outcomes on biological invasion. Data (left) on the three key dimensions of the problem, (1) spread, (2) impact (both its type and consequence) and (3) interventions are integrated in a set of workflows that combine primary evidence in informatics infrastructure. Data providers are multiple and include for example GBIF, GRIIS, CABI – Invasive Species Compendium, the IUCN and the World Database on Protected Areas (WDPA). Currently data on interventions for invasion and their effectiveness are poorly collated with no dedicated infrastructure. Integration and delivery (centre) are at the core of the framework. Data, with the support of models, are used to predict occurrences or abundances of invasive alien species across pathways of introduction and spread (including establishment) and over contiguous spatio-temporal units, representing the Species Populations Essential Biodiversity Variables (EBVs) for invasive alien species (GEO BON). This is supplemented with data and essential variables that capture ecosystem functions and sensitive priority areas impacted by invasion, as well as data on management actions to predict impact and quantify intervention effort. Indicators (right) build on the delivered invasion-relevant Essential Biodiversity Variables and are

Box 6 22

Figure 6 20

populated using modelled predictions with associated uncertainty on spread, impact and interventions (Vicente *et al.,* 2022). Response (lower left) consists of the four major interventions – prevention, eradication, management and prioritization. These activities are guided by decision-support tools and products (such as alien species distribution maps for protected areas and location-specific automated alerts for new invasions) provided from integration and delivery directly or *via* indicators. The responses in turn deliver much-needed new data, including data on intervention effort and success. From McGeoch & Jetz, (2019), https://doi.org/10.1016/j.oneear.2019.10.003, under Copyright Elsevier.

support the summary for policymakers of the IPBES Global Assessment (IPBES, 2019c); and have been considered to various degrees in national reporting (Secretariat of the CBD, 2020; J. R. U. Wilson *et al.,* 2018). Proposed headline indicators for monitoring the implementation of the Kunming-Montreal Global Biodiversity Framework have been published by the CBD (2022b), including a specific headline indicator for biological invasions "6.1 Rate of invasive alien species establishment".

Indicators of biological invasion are broadly classified into indicators of (1) the drivers that facilitate biological invasion, (2) the size of the invasion problem (pressure indicators), (3) impacts on biodiversity and society (state indicators) and (4) societal responses to invasion (response indicators; Butchart *et al.,* 2010; McGeoch *et al.,* 2010a; **Table 6.2**). Under a theory of change framework, response indicators are now further subdivided (into input process, output, outcome, impact) to capture the stages of implementation necessary to bring about the desired progress (OECD, 2019; J. R. U. Wilson *et al.,* 2018; **Table 6.11**).

Although central to tracking the success of interventions to prevent and reduce the harm caused by invasive alien species, the development, adoption and fitness for purpose of invasion indicators has to date been inadequate (Vicente *et al.,* 2022). No existing indicators meet all the criteria ideal for robust, policy-relevant indicators (Vicente *et al.,* 2022). Challenges also include invasive alien species indicators that are not supported by robust and repeatable scientific methods, a lack of indicators to report on some important aspects of the problem, and indicators that are reliant on increasingly old data, which as a result are not able to report on recent progress (Vicente *et al.,* 2022). Although a number of intergovernmental and research partnerships have supported this endeavour over the last decade, including GBIF, IUCN Species Survival Commission (SSC) ISSG and GEO BON, two key factors are responsible for the slow progress. First, there has not yet to date been widespread agreement and adoption of a coherent, fit for purpose suite of indicators that can be used for long-term reporting **(Table 6.2)**. Second, there has to date been no institutional home with the resources and capacity to drive the research and reporting needed to sustain a robust suite of invasive alien species indicators (Vicente *et al.,* 2022). One of the evident outcomes of this is that the multiple indicators identified in CBD-related documentation change from reporting period to reporting period, and some are not able to be delivered or updated at the end of reporting cycles.

The options for strengthening the information value of invasive alien species indicators and their relevance for policy are clear. These include:

- Invest in the on-ground monitoring systems needed to deliver up to date information on the identity, spread and impacts of invasive alien species; and on the implementation and effectiveness of responses, including the implementation and effectiveness of management actions (Latombe *et al.,* 2017);
- Complete the research needed to support robust scientific formulations of indicators, the metrics on which they based, how they are modelled and interpretation of the uncertainty associated with them (Jetz *et al.,* 2019; McGeoch & Jetz, 2019);
- Establish a stable partnership to support invasion indicators that has the scientific expertise, data and analytic capacity and resourcing necessary to sustain these indicators over the long-term;
- Support the open infrastructures, data sources and collation processes required to aggregate and inform invasive alien species indicators, such as GBIF and the Global Register for Introduced and Invasive Species that jointly provide the data foundational to informing on invasive alien species (Pagad *et al.,* 2018);
- Assess and progress the extent to which each indicator can be downscaled and expressed at country level and the extent to which they are suitable for use at a national scale (J. R. U. Wilson *et al.,* 2018).

Table 6 11 **Categories of currently used invasive alien species indicators at a global scale, their information content and development needs.**

The indicators listed are phrased broadly to represent multiple closely related indicators that have been expressed in slightly different ways across the literature, policy documentation and historical, current and proposed reporting cycles.

Indicator category	Indicator expressed in an inclusive general form, encompassing relevant alternative formulations of closely related indicators	Data sources	Development needs
Driver	Trends in pathways of introduction and spread	No current FAIR source	Although raw trends can be produced, research is needed to develop these into a robust indicator with estimates of uncertainty (McGrannachan *et al.,* 2021) GRIIS has the potential to inform this indicator in future
Pressure	Trends in numbers and spatial distribution of invasive alien species and their impacts	GRIIS GBIF First Records	Further research to deliver downscaling to countries
State	Trends, mechanisms and severity of invasive alien species impacts	Environmental Impact Classification for Alien Taxa (EICAT) GRIIS GBIF	IUCN Red list Index for invasive alien species is well established EICAT progressing but still under development Downscaling to ensure relevance to countries required
Response and Theory of Change sub-categories (section 6.2.1)			
Input	Trends in the allocation of resources towards the prevention or control of invasive alien species	IUCN SSC ISSG	The methodology could be improved through peer review and further development
Process	Trends in establishment and national adoption of international agreements relevant to the prevention and control of invasive alien species	IUCN SSC ISSG	Reaching saturation as the majority of countries adopt most agreements, but still room for improvement on the most recently adopted (2010) relevant convention (BWM Convention)
	Trends in numbers of countries with national legislation and other policy measures relevant to the prevention and/or control of invasive alien species	IUCN SSC ISSG	Further research and development are needed to assess cross-country comparability of policy instruments and their fit for this purpose
Output	Trends in the prevention, eradication and control of invasive alien species	No current FAIR data source Data largely not been collected and collated by countries	Disaggregation is needed for priority sites
	Growth in information relevant to informing policy on invasive alien species prevention and control	GBIF First Records GRIIS EICAT	There is potential for disaggregation from a global indicator of information status on species populations
Outcome	Trends in successful eradications	Database of Islands and Invasive Species Eradications (DIISE)	Currently limited to birds and mammals on islands Requires taxonomic and geographic expansion
Impact	Improvement in conservation status of species threatened by invasive alien species	IUCN Red List of Threatened Species	Requires expression at sub-global scales

6.7 TRANSFORMATIVE OPTIONS FOR ADDRESSING THE PROBLEM OF BIOLOGICAL INVASIONS

This section addresses the following question: What will it take to tip the current systems – including socio-institutional, socio-technical and socioecological systems – that drive and manage biological invasions in the direction of sustainability (Loorbach *et al.,* 2017; Westley *et al.,* 2011)? The section begins by describing what integrated governance for biological invasions is and why such an approach is relevant for biological invasions. It also suggests how this approach could be implemented using a set of strategic actions and governance system properties that will bring about transformative change, challenges to setting these actions in motion and how these could be overcome.

Sustainability science has emerged as an applied field in response to the need for sustainable development and acknowledging the complexity of the socioecological systems that need to be governed and managed in order to achieve it (Clark & Harley, 2020; Loorbach *et al.,* 2017). The problem of invasive alien species is one instance of a threat posed to both society and the environment because of unsustainable development. Invasive alien species are a direct driver of nature's decline (IPBES, 2019c), and tackling these is therefore key to bending the curve of biodiversity loss. Therefore, invasive alien species as a problem share many of the features of sustainable development challenges, and an awareness of the risks posed by these is essential to the effective delivery of several of the SDGs (in particular, goals addressing the conservation of marine biodiversity (Goal 14) and terrestrial biodiversity (Goal 15, including but not restricted to target 15.8), food security (SDG 2), sustainable economic growth (SDG 8), sustainable cities (SDG 11), as well as climate change (Goal 13) and health and wellbeing (Goal 3)).

Many of the options for achieving goals and targets for invasive alien species will be enabled by systemic changes that parallel and reinforce the solutions needed to achieve sustainability more broadly (Chan *et al.,* 2020; S. Díaz *et al.,* 2019). Transformative change becomes necessary to achieve sustainable management of biological invasions because, like other key environmental threats, biological invasion is driven by demographic, social, economic and technological factors (Visseren-Hamakers *et al.,* 2021; **Chapter 3**, **sections 3.3** and **3.6**).

This assessment therefore builds on the sustainability science framing of the IPBES conceptual framework and enablers of transformative change (S. Díaz *et al.,* 2019; Scoones *et al.,* 2020): To reverse nature's decline while addressing inequality, a "fundamental, system-wide reorganization across technological, economic and social factors making sustainability the norm" (S. Díaz *et al.,* 2019). In this context, governance is the "formal and informal (public and private) rules, rulemaking systems and actor networks at all levels of human society that enable transformative change" (Visseren-Hamakers *et al.,* 2021). For invasive alien species, transformative change depends on a system-wide reorganization, including technological, normative, economic and social factors, needed to achieve the goals enshrined in multilateral agreements and national strategies.

6.7.1 Integrated governance can bring about transformative change that improves the management of biological invasions

To bring about such system-wide reorganization for managing biological invasions, the approach could focus on the "deeper system properties" (Leventon *et al.,* 2021; Meadows, 1999) that characterize biological invasion governance. The full suite of governance models, policy instruments and support tools and methods identified in this chapter **(Table 6.1)** are available as options which, in combination, can be drawn on to achieve this ambition. These include (*sensu* Scoones *et al.,* 2020):

1. structural options that involve fundamental changes to the way policy and management of biological invasions is organized, legislated, regulated (**sections 6.3** and **6.5**);

2. systemic options that involve "changes targeted at the interdependencies of specific institutions, technologies and constellations of actors across scales and geography to steer complex systems" of stakeholders and Indigenous Peoples and local communities contributing to, influencing and affected by invasive alien species (**sections 6.2** and **6.6**); and

3. enabling options that "foster the human agency, values and capacities necessary to manage uncertainty, act collectively, identify and enact pathways" to futures where the risks and negative impacts of invasive alien species are substantially reduced (**sections 6.2** and **6.4**).

As defined in **Box 6.5**, integrated governance for biological invasions means establishing relationships between the roles of actors, institutions and instruments and involving, as appropriate (in other words the specific features will depend on the national and local contexts), all those elements of the socioecological system that characterize biological invasion and its management, for the purpose of identifying the strategic interventions needed to improve prevention and

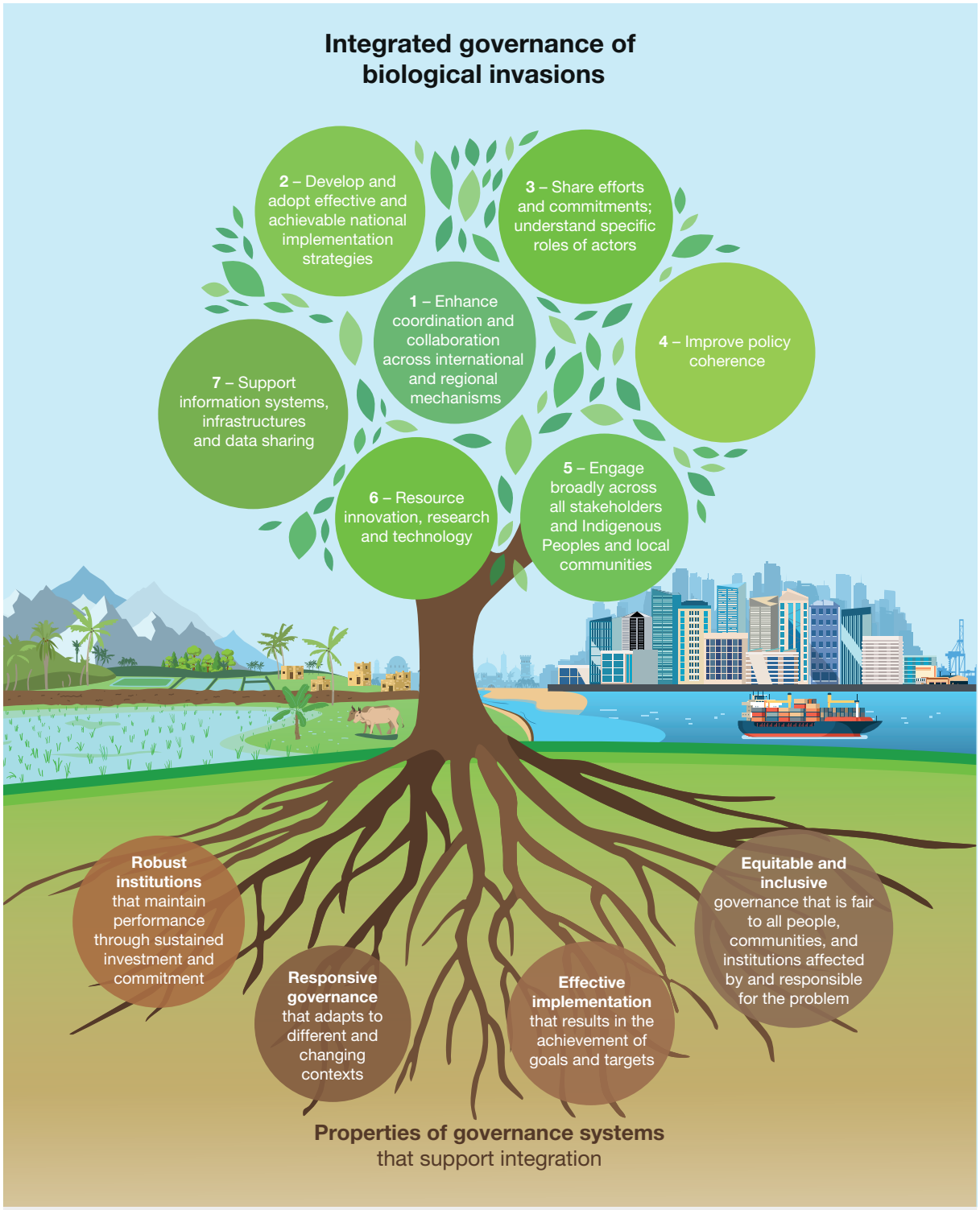


Figure 6 21 **Integrated governance for biological invasions.**

A context-specific integrated governance approach of biological invasions is enabled by a governance system with properties that support integration and a set of strategic actions that together are designed to bring about the progress needed to meet national and international goals and targets for biological invasions. Integrated governance is rooted (below) in four essential properties of governance systems that support the strategic actions (above) to be achieved. Together, the properties and actions will bring about the step change needed for effective and sustainable management of biological invasions. Integrated governance for biological invasions reinforces the enabling conditions identified as necessary to fulfil the 2030 mission of the Kunming-Montreal Global Biodiversity Framework. An integrated governance approach activates specific strategic actions that promote transformative change to meet the goals of preventing and controlling biological invasions.

Figure 6 21

The strategic actions (branches) are:

1. Enhance coordination and collaboration across international and regional mechanisms.
2. Develop and adopt effective and achievable national implementation strategies.
3. Share efforts and commitments, and understanding of the specific roles of all actors.
4. Improve policy coherence.
5. Engage broadly across governmental sectors, industry, the scientific community, Indigenous Peoples and local communities and the wider public.
6. Support, fund and mobilize resources for innovation, research and environmentally sound technology.
7. Support information systems, infrastructures and data sharing.

The proposed strategic actions are enabled when the system-wide properties of governance (roots) are robust, equitable and inclusive, responsive and focused on effective implementation. The numbers on the branches do not imply a ranking.

control outcomes **(Figure 6.21)**. While at face value this appears to be a monumental task, many of the processes and elements for preventing and controlling invasive alien species are already established and in play. Enhancing, strengthening and improving implementation and better integrating the actions and system properties that make up integrated governance for biological invasions could bring about a step change in progress.

Integrated governance for biological invasions is also establishing relationships between the roles of actors, institutions and instruments to ensure a shared, connected, coherent and differentiated effort to manage biological invasions **(Figure 6.23)**. It also involves the engagement of all the appropriate elements of the socioecological system that characterize biological invasion and their management to define the best strategies in those areas when invasive alien species impose socio-economic impacts (Bacher *et al.,* 2018). Last, it acknowledges that good governance, while essential to achieving sustainable outcomes for the prevention and control of invasive alien species, is somewhat of an experiment (Clark & Harley, 2020) and would therefore need to be adaptive as well as coordinated to facilitate learning (Brauman *et al.,* 2020). **Figure 6.21** illustrates "integrated governance for biological invasions" as the framework by which transformative governance (**Glossary**) for invasive alien species could be achieved, encompassing seven strategic actions and four governance system properties.

6.7.2 Strategic actions

6.7.2.1 Enhancing coordination and collaboration across international and regional mechanisms

The most important proactive (e.g., border control) and reactive (e.g., eradication) measures to address biological invasions are administered at the national or subnational level. However, the nature of biological invasions means that multilateral and transnational approaches are also needed. While there is no shortage of organizations focused on addressing the problem of biological invasions, one of their main limitations has been their disconnected nature. Cooperation amongst different regional and national efforts will not arise spontaneously and will need concerted leadership, resourcing and commitment from governments and institutions at the highest level (Leclère *et al.,* 2020; Ruckelshaus *et al.,* 2020; **section 6.2.3.1**). Therefore, establishing or enhancing global coordination mechanisms (similar to the Convention on the Conservation of Migratory Species of Wild Animals (CMS)) for biological invasions, or embedding this role into existing coordinating bodies (e.g., the CBD), are options for achieving one of the key strategic actions for transformative progress **(Figure 6.21)**. Such coordination mechanism could promote the exchange of best practices and other knowledge between regions and nations, help to establish the appropriate roles and responsibilities of actors (Stoett, 2007), enable global species listings and strengthen the effectiveness of the Inter-Agency Liaison Group on Invasive Alien Species. While the CBD currently covers invasive alien species as a cross-cutting issue, this assessment has amassed sufficient evidence to suggest the theme needs a more pronounced coordinating mechanism at the global level.

6.7.2.2 Developing and adopting effective and achievable national implementation strategies

Failure to adopt existing guiding principles (e.g., **Table 6.3**), and to implement legislation and action plans, have been a central impediment to progress on invasive alien species targets (**sections 6.2.2** and **6.3.1.4**). Implementation focused strategies for biological invasion management can assist in overcoming this hurdle **(Figure 6.21)**. This can be achieved by revisiting implementation strategies at all levels of governance, and in particular at those most relevant to the strategic actions identified in **Figure 6.21**. Options for this include, amongst others, consistent enforcement of relevant law (Chan *et al.,* 2020) and investment in monitoring and learning from the successes and failures of interventions **(Box 6.23)**.

Feeding this information into response-focused theory of change indicators, including indicators that track the allocation of resource inputs, the establishment and

Box 6 23 Overcoming the implementation gap for invasive alien species.

Two key hurdles to improving the management of invasive alien species, are:

1. the need for more effective prioritization of where and when to intervene, and
2. the lack of information on which interventions are most successful and in which contexts.

Both these hurdles can be overcome by generating essential data and knowledge on resource inputs, processes, outputs and outcomes (OECD, 2019) of efforts to manage invasive alien species **(Box 6.6; Figure 6.22)**.

Resource inputs: How much are governments and other responsible actors spending on invasive alien species management? What are the gaps in appropriately qualified, existing capacity and expertise that can be filled?

Processes: What coordination and oversight mechanisms are in place, from local communities to governments, to enable investment and ensure effective implementation of invasive alien species management?

Outputs and actions: What new or strengthened instruments are in place to improve policy coherence, to guide strategic investment and to adequately share and differentiate responsibilities for invasive alien species prevention and control?

Outcomes: Has the rate of new introductions and newly established invasive alien species declined? Has their spread and impact been reduced?

A sustained information platform for invasive alien species can then deliver this information when it is needed and to where it is needed (**section 6.6.2.4**). With the data that are collated, instrumental indicators will be able to report on progress and, based on the knowledge they provide, to iteratively refine and improve the efficiency of responses (i.e., adaptive governance, planning and management; **Figure 6.22**). Together, this approach can catalyse the collection of the information most needed to manage invasive alien species, reduce uncertainty and improve efficiency in decision-making. It can also support reporting on sustainable development and progress to meeting national and multilateral goals and targets for invasive alien species. Clearly linked to and embedded in national strategies for invasive alien species, this approach can leverage the responses needed to overcome current implementation gaps and provide a backbone for integrated governance.

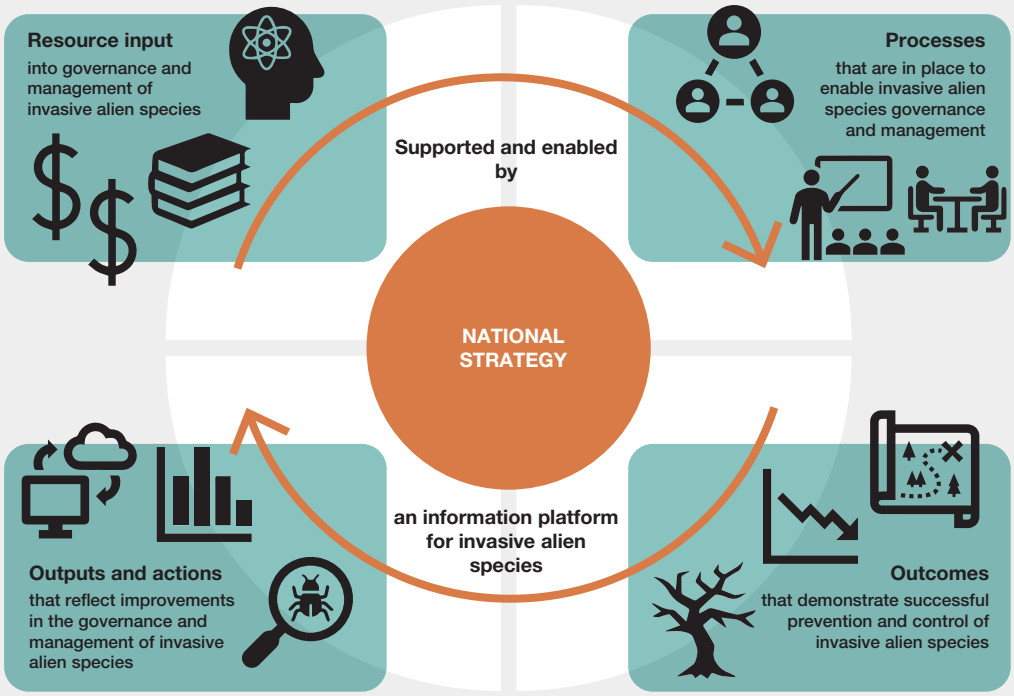


Figure 6 22 **Monitoring progress in four types of responses to invasive alien species to leverage activity to overcome the implementation challenge.**

If these responses are effective, they should manifest in a reduction in the numbers, spread, impacts and costs of invasive alien species.

uptake of implementation processes, and the outputs and outcomes of these interventions are in line with the Kunming-Montreal Global Biodiversity Framework (CBD, 2022a; OECD, 2019; J. R. U. Wilson *et al.,* 2018; **Table 6.11**; **Box 6.23**). While a strategy is necessary for effective governance at multiple levels and in multiple sectors (**section 6.3**), national scale strategy can be particularly instrumental in achieving the scope and cohesion needed to implement action both above (multilateral) and below (at local and subnational) national government.

6.7.2.3 Sharing efforts and commitment, and understanding the specific role of all actors across governments, Indigenous Peoples and local communities, and industries

The principle of shared, connected and specific roles builds on the fact that individuals, communities, industry and governments share the benefits from nature and therefore also share the responsibility of mitigating the risks imposed by drivers of change such as invasive alien species. This definition is a contextual application of the international environmental law principle of common but differentiated responsibilities (Stone, 2004) as it considers all parties as equally responsible for addressing the problem, but their knowledge and tasks are clearly differentiated based on their relationship to the problem; this is fundamental for a successful application of integrated governance for biological invasions **(Figure 6.23)**.

The management of biological invasions is a collective effort where individuals, communities, industry and governmental agencies play a unique but coordinated role. Such coordination builds from engagement of all actors concerned with the mitigation needed to avoid environmental, economic and health impacts from invasive alien species **(Figure 6.23)**. This can be achieved through a co-production approach that acknowledges that all

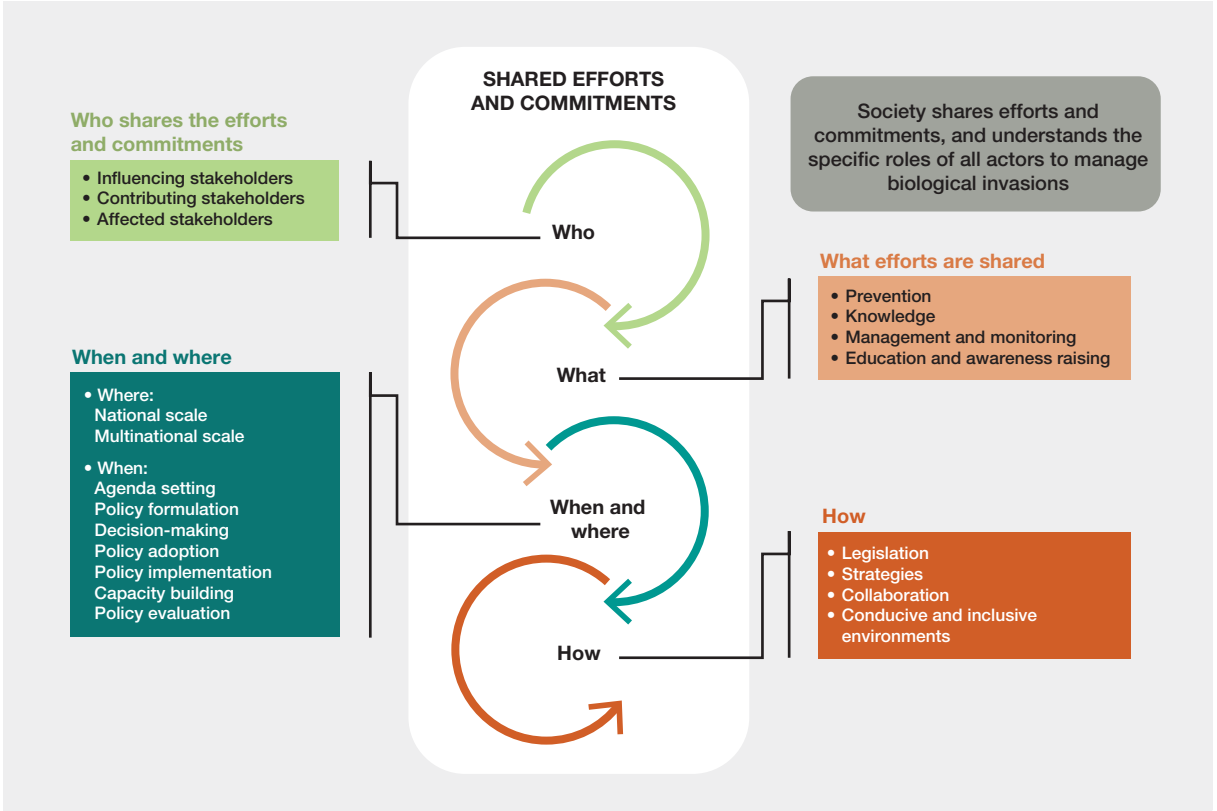


Figure 6 23 **Sharing efforts and commitments, and understanding the specific role of all actors for the prevention and control of invasive alien species.**

This approach emphasizes that people, knowledge, governance and policy instruments have a specific role and need to be connected. The shared efforts and commitments principle means that all actors are part of the solution, so that actions to manage invasive alien species are connected (i.e., there is effective flow of communication between all actors) between people, knowledge, governance approaches and policy instruments. The understanding of the specific roles of all actors, is an idea based on the principle that every institution and stakeholder have a specific part to play in the coordinated and coherent strategy that is the integrated governance for biological invasions.

stakeholders involved hold relevant knowledge and expertise; and that defines strategic connections between people, knowledge, governance approaches and policy instruments (Lemos *et al.,* 2018; Turnhout *et al.,* 2020).

Concrete actions by industries involved in potential pathways for invasive alien species are necessary to increase compliance with current legislation, and voluntary codes of practice can limit the biosecurity risks posed by industrial actors. International organizations can help here: for example, tourism can operate as a pathway and the World Tourism Organization (UNWTO) was asked at CBD COP15 to examine collaborative efforts to reduce invasive alien species introductions. The engagement of the general public *via* citizen science platforms, awareness campaigns, or community-driven eradication campaigns is critical for generating shared efforts and commitments by understanding the specific role of all actors play for addressing the invasive alien species problem. Also critical is the context-contingent involvement of specific stakeholders (e.g., agriculture producers, hobby associations, leisure groups) and Indigenous Peoples and local communities. The engagement and empowering of Indigenous Peoples and local communities is a crucial part of developing inclusive systems that recognize the rights of these communities and their knowledge, practices and values in the management of biological invasions. Such engagement strategies can generate ownership of biological invasion management while supplementing surveillance and management efforts.

6.7.2.4 Improving policy coherence

Global environmental change (with climate change as an example)

Invasive alien species impacts can compound the negative effects of climate change on good quality of life, acknowledging that this outcome is dependent on the species, regions and local conditions involved (e.g., Bradley & Wilcove, 2009; Shabani *et al.,* 2020). It is important that the transformative change needed to prevent and control invasive alien species is not neglected in the current context of a necessarily strong policy focus on climate change. The direct effects of invasive alien species on biodiversity are one of the ways in which the consequences of climate change are translated into direct negative outcomes for nature's contributions to people and good quality of life. Although invasive alien species and climate change are projected to affect fewer species than land-use change, these drivers can interact to become critically important at local scales and can impact people directly (Leclère *et al.,* 2020). The integration of invasive alien species and climate change policy considerations through environmental governance more broadly are options supported by a groundswell in forward-looking thinking and strategy on how to achieve environmental sustainability. The integrated governance approach that focusses attention on the intersections, linkages and trade-offs – and the research, policy and governance instruments needed to achieve complex objectives – is an option for advancing this ambition (J. Liu, Dou, *et al.,* 2018). The exploration of governance arrangements across many different goals and drivers of change is an option for overcoming the multiple needs for building and maintaining reflexive (learning by self-reflection) governance capacity (Clark & Harley, 2020).

Coherence between sectorial policies and institutions

One of the main reasons behind the current failures to address biological invasions has been the strong sectoral silos between sectors that characterize policy regimes. This division has resulted in disjointed decision-making (**section 6.3.1.1**). The development of a coordinated biosecurity approach that blurs the traditional boundaries between sectors would help address environmental, health and agricultural challenges (Hulme, 2021). This cross-sector coordinated approach could provide a better way forward but is not without challenges. Collaborative, multisectoral and transdisciplinary approaches such as One Health (**Glossary**), Eco Health and One Biosecurity provide frameworks to achieve coordination between multiple sectors as well as across economies and cultures. Such coordination would facilitate the prevention and mitigation of the growing threats posed by invasive alien species. Promoting relationships between stakeholders and institutions is one option for achieving one of the key levers for transformative progress **(Figure 6.21)**. Improving policy coherence would help overcome current significant gaps in coverage of regulations targeting invasive alien species. It can also facilitate sharing efforts and commitment and understanding the specific role of all actors (**section 6.7.2.5**).

6.7.2.5 Engaging broadly across governmental sectors, industry, the scientific community, Indigenous Peoples and local communities and the wider public

General tools and approaches and frameworks exist for stakeholder engagement (**Chapter 5**, **section 5.2.1**). However, the purpose of engaging with different groups – the industrial sectors, the general public, Indigenous Peoples and local communities and the scientific community – differ **(Table 6.12)**. The design of effective engagement strategies will have context dependent elements and will take these different purposes into account (**Chapter 5**, **section 5.2.1**). The funding of

engagement activities can be built into management plans and budgets to support multiple purposes in the management of biological invasions. To be effective, engagement activities can also be included within monitoring and evaluation of invasive alien species management actions, so that progress can be tracked and strategies refined over time. In this way, the effectiveness of engagement activity can also be refined and improved over time. All these elements are important for public engagement and inclusion activities to effectively contribute to implementing an integrated governance approach for biological invasions **(Figure 6.21)**.

An understanding of stakeholder and Indigenous Peoples and local communities influence and interests and how stakeholders are likely to be involved in different stages of the biological invasion process is crucial to any attempt to engage, represent, empower and co-design biological invasion management plans, and directly engage stakeholders, including citizens, as equal partners. It is clear that communicative and consultative approaches can deliver significant benefits (Shackleton, Adriaens, *et al.,* 2019). In contexts where there are significant conflicts of values or mistrust between actors, or where significant buy-in will be required to implement governance measures, it is likely to be worthwhile investing in co-productive approaches. Policy design for dealing with the anticipated impacts of invasive alien species that is sensitive to the needs and perspectives of vulnerable groups, stakeholders and Indigenous Peoples and local communities can also help achieve social justice (Blythe *et al.,* 2018; Patterson *et al.,* 2018; Temper *et al.,* 2018).

6.7.2.6 Supporting, funding and mobilizing resources for innovation, research and environmentally sound technology

(1) Improved risk assessment

There is wide variability in the capacity to respond to biological invasions amongst countries (Early *et al.,* 2016). Such variability showcases considerable imbalance in the knowledge base and implementation of best practices. Addressing such an imbalance means tracking biological invasions beyond country boundaries (Latombe *et al.,* 2017), building on the idea of connecting knowledge systems *(point 3)*. However, knowledge sharing could be paired with capacity-building and transboundary and cross-sector risk assessment tools **(Figure 6.21)**. For example, intervention strategies could focus on slowing the rates of new introductions taking place at a regional scale (e.g., African Union, European Union, MERCOSUR, USMCA/CUSMA). Thus, it is necessary to define the regions with capability deficits to determine where and how multilateral and bilateral partnerships could be forged to support those countries with limited biosecurity capabilities (Hulme, 2021). Then, within connected regions, sharing insights on invasive alien species of relevance, border control principles and methods is critical for an effective regional approach to prevention (Hulme, 2011, 2020). More generally, a coordinated and nuanced approach to risk-assessments and intervention could be extended to a global context, taking lessons from the current efforts to prevent and contain the spread of the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2).

Table 6 12 **Engagement of stakeholders on biological invasions has a number of purposes and associated approaches and tools (options) that support the process.**

	Purpose of engagement to achieve:	Example options
1	Inclusive decision-making for biological invasions	Decision support tools (**Chapter 5**, **sections 5.2** and **5.4**), Deliberative multi-criteria analysis (**Chapter 5**, **section 5.2.2.1.j**), communication feedback systems (**section 6.3.1.4(5)**)
2	Public education and awareness raising about biological invasions	Training and risk-communication platforms (**Chapter 5**, **section 5.2.2.1** and **Table 5.6**)
3	Social learning and knowledge sharing about biological invasions; attempting to accommodate conflicting values	Co-design, co-creation and co-implementation of research and management actions (**Chapter 5**, **section 5.2.1** and **Figure 5.19**, **section 6.4.2**)
4	Coordination and collaboration for governance and management of biological invasions	Build shared trust, community-based management using adaptive management approaches (**sections 6.4.2**, **6.4.4**) and implementing appropriate, context-relevant network design for the governance structure (**sections 6.4.4.2**, **6.5.6**)
5	Surveillance and monitoring for early detection, data generation and evaluating the effectiveness of interventions for invasive alien species	Citizen science and citizen surveillance activities, including apps and data input portals (**Chapter 1**, **Figure 1.13** and **Box 1.15**; C**hapter 5**, **section 5.4.3.2** and **Table 5.6**, **section 6.6.2.1**; **Box 6.20**)

Developing new risk assessment tools (**Chapter 5**, **section 5.2.2.1.e**) also means employing coordinated regulatory instruments that support coherent governance for biological invasions **(Figure 6.21)** and address the fractured and disjointed approach to invasive alien species management resulting from policies that solely address issues within sectorial silos (Shine, 2007; Outhwaite, 2013; Hulme, 2021). As described in **section 6.7.2.7**, this integration could be achieved by focusing on the links between risk assessment tools of legal and regulatory instruments currently within human, animal, plant and environmental sectors.

(2) Forecasts, scenarios and models

The development of forecasting tools based on drivers that facilitate biological invasions (Essl, Lenzner, *et al.,* 2020), or mechanistic models (Sarà *et al.,* 2013; Chapman *et al.,* 2017) is vital. These forecasting tools should also focus on predicting the impacts of invasive alien species by considering the synergies in interacting drivers including invasive alien species, invasive alien species interactions and impacts (Gaertner *et al.,* 2014). These tools would then need a description of the possible scenarios of change based on shifts of the drivers in facilitating biological invasions (**Chapter 3**, **section 3.1.1**). The scenarios would describe the alternative trajectories for biological invasions within the context of complex and uncertain future socioecological developments (Alien scenarios, 2021; Roura-Pascual *et al.,* 2021).

Incorporating a wide range of modelling and scenario techniques could enable assessment of multiple pathways across spatial scales and through integration of different domains (i.e., a nexus approach; J. Liu, Hull, *et al.,* 2018). Currently joint scenario and modelling studies have a strong focus on correlative modelling approaches using single driver assessments and exploratory scenarios[19] (**Chapter 1**, **section 1.6.7.3**). Other gaps, such as the vast absence of policy-screening and target-seeking scenarios, quantifiable sustainability and policy targets for biological invasions or the widespread lack of process-based models have to be filled in order to understand the needs for and development of transformative change pathways that account for the adverse effects of invasive alien species on biodiversity, nature's contribution to people and good quality of life (**section 6.6.1.6**). Existing initiatives for transformative change related to biodiversity change (Leclère *et al.,* 2020), climate change (e.g., Burch *et al.,* 2014; Schot & Steinmueller, 2018) or food security (A. Muller *et al.,* 2017) can be taken as blueprints for the steps that can be taken to use scenarios and models to support transformative change.

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

(3) Innovative science and environmentally sound technologies to support prevention and control

The continued increasing rate in invasive alien species introductions (**Chapter 2**) highlights the need for innovative science and technologies to support the detection of and rapid response to invasive alien species (Chown *et al.,* 2015; NISC, 2016). There is a need for development of new approaches but also improvements in the effectiveness and cost-efficiencies of existing methods. In the context of technological innovations **(Figure 6.21)**, these might come from efforts or programmes focused on detection (using visual, chemical, acoustic, or genetic attributes) and/or identification for military intelligence, or human health purposes, which have not traditionally focused on invasive alien species (Martinez *et al.,* 2020; Conservation X Labs, 2017). The deployment of artificial intelligence driven internet monitoring systems for invasive species is another powerful technological advancement for the early detection of sources of known invasive alien species prior to their potential entry (Suiter & Sferrazza (2007) for an example of the application of such technology). A fundamental dimension of this development is to ensure the applicability of current technologies in diverse contexts (Martinez *et al.,* 2020; Kamenova *et al.,* 2017; **section 6.3.1.4**).

6.7.2.7 Support information systems, infrastructures and data sharing to connect knowledge systems using digital processes and international partnerships

Current understanding of the biological invasion process is adequate for taking preventive effective action. However, there remain key data, information and knowledge gaps in invasion biology and social science for bringing about widespread progress across invasion stages that could be beneficial in maximizing the efficacy of actions **(Table 6.10)**. Information systems and sharing are essential for the integrated governance for biological invasions (**Figures 6.21** and **6.23**) as these would (i) provide direction for filling key data and information gaps, (ii) enable open and equitable access to information across well and poorly resourced regions and stakeholders, (iii) facilitate the research and capacity-building needed to respond to ongoing and changing demands for information on the multiple dimensions of the problem of invasive alien species and (iv) mobilize the knowledge needed to support effective implementation of prevention and control measures (Caniglia *et al.,* 2021). Importantly, to avoid wasted investment in information platforms that collapse as resourcing changes across funding cycles, a mechanism for long-term, sustained support for an information sharing system is desirable (**sections 6.2.3.1(3)** and **6.6**).

6.7.3 Promoting a conducive environment and enabling conditions for integrated governance and transformative change

Creating a conducive environment to achieve the change that is needed is an important part of effective prevention and control of invasive alien species **(Figure 6.24)**. Good governance systems are characterized by being effective, robust, responsive and equitable (Bennett & Satterfield, 2018), and employing the strategic actions and priority interventions that bring about these characteristics **(Figure 6.24)**. These four qualities can be achieved by drawing on a broad suite of policy instruments, methods and support tools, using formal and informal decision-making structures and facilitated by processes such as negotiation, conflict resolution and knowledge sharing, particularly at local scales.

Designing, building and strengthening governance systems for biological invasions with effective, robust, responsive and equitable purposes in mind is, therefore, likely to be one of the most important determinants of progress to achieving goals for invasive alien species management. Indeed, several of the factors identified in this section, based on invasive alien species evidence, reinforce the enabling conditions identified as necessary to the 2030 mission for the Kunming Montreal Global Biodiversity Framework (CBD, 2021a), namely:

- Building participation of all stakeholders, including Indigenous Peoples and local communities;
- Inclusion of multiple sectors in decision-making;
- The need for synergies across relevant multilateral agreements and policy coherence and effectiveness monitoring;

Figure 6 24 **The conditions that support integrated governance for biological invasions reflecting the desirable, inter-dependent qualities of governance systems (i.e., the properties of governance systems in Figure 6.21).**

Adapted from Bennett & Satterfield (2018), https://doi.org/10.1111/conl.12600, under license CC BY 4.0.

- The establishment of cooperation mechanisms that enable collective action;
- Active involvement of sub-national and local decision-making nodes and clear assignment of roles and responsibilities;
- Preventing indirect and negative telecoupling effects (also called spill over processes), such as invasive alien species themselves;
- Recognition of the challenges at the highest levels of government and political will to act.

6.7.4 Conclusion

This chapter, supported by evidence from policy studies and other fields, and reflecting knowledge gained from previous chapters, has identified numerous options which could substantially improve invasive alien species prevention and control across multiple scales, levels of governance and sectors. It is important not to underestimate the immense threat to nature, nature's contributions to people and good quality of life posed by invasive alien species, which, at their worst are a form of persistent or irreversible pollution that can be considered as a "kind of calculable oppression" of future generations (Dasgupta, 2021; Sen, 1982). Optimal governance and policy-making conditions can be formed by policymakers, experts and citizens who are cognizant of the diverse existing approaches. Implementing integrated governance for biological invasions will only be achieved through deep cross-disciplinary discussions and planning and sustained, vigilant effort. A new focus on integrated governance stands to benefit not only invasive alien species management, but provides exciting paths towards new mechanisms and opportunities for communities to sustain good quality of life while addressing the intertwined threats to biodiversity that also threaten human civilization.

The overarching message of this chapter and of the IPBES invasive alien species assessment is clear: though there has been success in understanding and managing biological invasions, a robust, sustained and socially inclusive global commitment is necessary to avoid the most harmful impacts of invasive alien species on nature and people. The goals on reducing invasive alien species adopted by the parties to the CBD as part of the Kunming-Montreal Global Biodiversity Framework in late 2022 are attainable, but there is no time to waste in their earnest pursuit.

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