16 Moving Toward Global Strategies for Managing Invasive Alien Species

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Abstract

As human communities become increasingly interconnected through transport and trade, there has been a concomitant rise in both accidental and intentional species introductions, resulting in biological invasions. A warming global climate and the rapid movement of people and vessels across the globe have opened new air and sea routes, accelerated propagule pressure, and altered habitat disturbance regimes, all of which act synergistically to

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trigger and sustain invasions. The complexity and interconnectedness of biological invasions with commerce, culture, and human-mediated natural disturbances make prevention and management of invasive alien species (IAS) particularly challenging. Voluntary actions by single countries have proven to be insufficient in addressing biological invasions. Large gaps between science, management, and policy at various geopolitical scales still exist and necessitate an urgent need for more integrative approach across multiple scales and multiple stakeholder groups to bridge those gaps and reduce the impacts of biological invasions on biodiversity and human well-being. An evidence-based global strategy is therefore needed to predict, prevent, and manage the impacts of IAS. Here we define global strategies as frameworks for evidence-based visions, policy agreements, and commitments that address the patterns, mechanisms, and impact of biological invasions. Many existing global, regional, and thematic initiatives provide a strong foundation to inform a global IAS strategy. We propose five recommendations to progress these toward global strategies against biological invasions, including better standards and tools for long-term monitoring, techniques for evaluation of impacts across taxa and regions, modular regulatory frameworks that integrate incentives and compliance mechanisms with respect to diverse transcultural needs, biosecurity awareness and measures, and synergies with other conservation strategies. This proposed approach for IAS is inclusive, adaptive, and flexible and moves toward global strategies for better preventing and managing biological invasions. As existing research-policy-management networks mature and others emerge, the accelerating need for effective global strategies against biological invasions can finally be met.

Keywords

Globalization · Frameworks · Networks · Policy · Regulation · Stakeholder engagement

16.1 Introduction: A Global Approach to a Global Challenge

Vast shifts in biodiversity are occurring in nearly every ecosystem as increasing global interconnectedness and the inexorable warming of land, aquatic, and ocean habitats due to human-caused climate change give rise to more biological invasions and the poleward movement of uncounted (and uncountable) species (Sorte et al. 2010; Bates et al. 2014; Hulme 2017; Seebens et al. 2017; Pyšek et al. 2020). People and products are moving ever more rapidly between global transport nodes, often with organisms as both intended and unintended passengers that readily survive these journeys and quickly become established within new territories. Human-modified habitat disturbance often aids both their movement and establishment. As thousands or tens of thousands – or more – species invade communities composed of both native and previously introduced plants and animals, we expect profound shifts in ecological networks, trophic dynamics such as predator-prey regimes, and virtually every other aspect of ecosystem structure and function.

Much less predictable, but perhaps increasingly powerful, extreme weather events (e.g., cyclonic storms and floods) or natural disasters such as tsunamis can also redistribute materials and organisms into highly disturbed and far-flung environments. For example, with constantly growing and expanding human populations, natural disasters have far greater probabilities of unexpected, and perhaps unpredictable, consequences relative to species dispersal and thus invasions. Since the 1950s, the mass production of styrene, fiberglass, and other plastic products – from food packaging to household goods to automobiles – has become a dominant component of our waste streams. Vast amounts of plastic are concentrated in megacities, many of which are located on or near the coasts. This largely non-degradable material ultimately ends up in estuaries and seas and gets further distributed globally. In March 2011, the Great East Japan Earthquake and Tsunami swept away cities and towns,

including ports, harbors, and aquaculture farms, on the Pacific coast of northern Honshu, with water currents carrying millions of plastic, metal, and wood items forming marine debris. Prior to that, the last major tsunami in the region occurred in 1933 – before the plastic era. The associated debris did not act as a vector for invasive species as the plastic debris associated with the recent tsunami did. In 2012, the debris field from Japan began to arrive in North America and the Hawaiian Islands. A relatively small sample (634 items) of the landed debris revealed that nearly 400 living Japanese marine species had successfully crossed the North Pacific using debris as dispersal agents (Carlton et al. 2017, 2018). By 2013–2014, the debris field consisted almost entirely of plastic objects (the wood having been destroyed by shipworms and most metal products having sunk) (Treneman et al. 2018). As of 2018, debris with living Japanese species continued to travel far and wide. The proliferation of a non-biodegradable substance at the land-sea interface, susceptible to movement by tsunami or the increasing number and strength of human-mediated storms, has thus created a passive novel vector for long-distance dispersal of species – with much greater spatiotemporal longevity than ever witnessed in nature (Carlton et al. 2017, 2018). This is a prominent example in the Anthropocene of the increased opportunities for invasive organisms and novel vectors, including passive unintentional transport, available to spread into regions where they never previously occurred. Such new dimensions of the global invasion problem call for innovative solutions.

While globalization has been underway for centuries and has intensified since the period of "great acceleration" of the 1950s, invasion science has been unable to halt the introduction, spread, and ecological, economic, and human health impacts of invasive alien species (IAS) around the world (Seebens et al. 2017). Our knowledge and awareness of the threats posed may be growing, but our global capacity to reverse trends and prevent and minimize impacts is limited in the absence of a better strategic vision, globally coordinated efforts, and legally binding targets. Similarly, although knowledge available on the threats invasive species pose has exponentially increased since the late 1980s (Pyšek and Richardson 2010; Vilà et al. 2010; Pyšek et al. 2012; Ricciardi et al. 2013; Gaertner et al. 2014; Table 16.1), large gaps still exist between science, policy, and management. There is thus an urgent need for more integrative approach, across multiple scales and stakeholder groups, to bridge these gaps and reduce the impacts of biological invasions on biodiversity and human well-being. In a globalized world, how countries manage invasive alien species is critical to prevention, including how donor and recipient countries coordinate efforts to reduce introductions of new invaders (see Glossary, Box 16.1). Undoubtedly, differences in wealth among countries and the ability to build institutional capacity for international cooperation can limit coordination (Early et al. 2016; Latombe et al. 2017). Large mismatches may occur across borders in national legal or regulatory frameworks (Nuñez and Pauchard 2010), and these need to be considered when formulating global approaches. More research is needed to better understand how IAS introductions and impacts differ between developed and developing countries and whether smaller economies have fewer IAS introductions. Regional, bilateral, and multilateral regulatory instruments, including the Convention on Biological Diversity (CBD), have emphasized the need to prevent the movement of IAS. Lesser developed countries may not have the resources, technology, or capacity to develop comprehensive quarantine measures, but they may have lower levels of invasions due to lower introduction efforts and lower historic trade (Nuñez and Pauchard 2010). However, other imbalances may exist between trading partners, where the partner with less influence and capacity may not be empowered to enforce safeguarding regulations or restrict imports that present a risk for species introduction. While preventing export in the first place would be ideal, all nations are already overburdened to prevent importing IAS, and what leaves a country's jurisdiction is beyond the management and regulatory capacity of even the most advanced countries in the world. Given this scenario, local actions need to be well-coordinated with global strategies to be more effective

Table 16.1 Existing networks: knowledge

Acronym	Full name	Stated purpose	Spatial scale	Temporal scale	URL
AS	Alien scenarios	Develop the first global, continental, and regional scenarios and models for biological invasions in twenty-first century Assess the effectiveness of regulations for invasive alien species Evaluate the future impacts of biological invasions on environment and livelihoods	Global	1 year (2019–ongoing)	alien-scenarios.org/
EICAT	Environmental impact classification of alien taxa	1. Identify taxa that have different levels of environmental impact 2. Facilitate comparisons of the level of impact among regions and taxonomic groups 3. Facilitate predictions of potential impacts in target region and elsewhere 4. Prioritize management actions 5. Evaluate management methods	Global	5 years (2015–ongoing)	iucn.org/theme/species/our-work/invasive-species/eicat
GUBIC	Global urban biological invasion consortium	To uncover how urbanization shapes, and is shaped by, movement of species around the world. Focuses on how environment, city structure, biogeography, history, trade, economics, and governance all shape biodiversity and its benefits in cities	Global	2 years (2018–ongoing)	utsc.utoronto.ca/projects/gubic/
ICES	International Council for the Exploration of the Sea	To advance and share scientific understanding of marine ecosystems and services they provide and to generate advice for conservation, management, and sustainability goals	Global	118 years (1902–ongoing)	ices.dk/
InvasiBES	InvasiBES: Understanding and managing the impacts of INVASIve alien species on biodiversity and ecosystem services	InvasiBES aims to better understand and anticipate multifaceted impacts of invasive alien species on biodiversity and ecosystem services and to provide tools for their management. It combines primary data and models across habitats (terrestrial, freshwater, and marine) and scales (continental and local)	Multi-continental (EU, United States)	3 years (2019 to 2021)	elabs.ebd.csic.es/web/invasibes
MIREN	Mountain invasion research network	To understand the effects of global change on species' distributions and biodiversity in mountainous areas	Global	15 years (2005–ongoing)	mountaininvasions.org/

Acronym	Full name	Stated purpose	Spatial scale	Temporal scale	URL
NEON	National Ecological Observatory Network	To collect and provide open data that characterize and quantify complex, rapidly changing ecological processes	Continental (USA; 48 lower states, HI&PR)	8 years (2012–ongoing)	neonscience.org/
SEICAT	Socioeconomic impact classification of alien taxa	1. Identify the magnitude of socioeconomic impacts of alien taxa. 2. Consider context dependency of impacts and comparisons among regions and taxa. 3. Facilitate predictions of potential impacts in the target region and elsewhere. 4. Aid in prioritization of alien taxa and relevant introduction pathways for management actions.	Global	18 months (2018–ongoing)	Bacher et al. (2018)

Box 16.1 Glossary of Terms

Common gardens:	Experiments conducted either in the field or greenhouse in order to test for differentiation among any set of genetically distinct plant groups in a relatively homogeneous environment
Donor regions:	Donor regions are the country or region from which an invasive species or a particular genetically identified population originates
Ecosystem services:	The benefits that people receive from nature. More recently, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) introduced Nature's Benefits to People in 2015 (Díaz et al. 2015a, b)
Globalization:	The growing interdependence of the world's economies, cultures, and populations, brought about by cross-border trade in goods and services, technology, and flows of investment, people, and information (Peterson Institute for International Economics, piie.com)
Global governance:	Political cooperation among countries that aims to negotiate responses to shared challenges affecting more than one state or region
Global strategies:	Evidence-based policy agreements that coordinate multinational efforts to address patterns, mechanisms, and impacts of biological invasions
Invasive alien species:	Species, lower taxa, or genotypes introduced to an ecosystem where they are nonindigenous and likely to cause harm to biodiversity, the economy, public health, or the environment. However, there is no globally accepted definition of "harm," and often no generally accepted definition even within a single country
Phytosanitary:	Refers to the health of plants, especially with respect to the requirements of international trade
Recipient regions:	Recipient regions are the country, region, or ecosystem where the invader is introduced and established

and efficient in the use of limited budgets and resources, and more developed countries need to invest in supporting global action for the prevention of IAS.

Effective leadership to prevent and manage IAS is complicated by its multi-scalar distribution across geopolitical boundaries and the diverse political, economic, and cultural perspectives of stakeholders in donor and recipient regions that cause and suffer from biological invasions. The complexity and interconnectivity of biological invasions with culture, commerce, and political exigencies make their prevention and management particularly challenging. Invasions can directly affect humans by impacting health and socioeconomic systems (Bacher et al. 2018). To prevent and reduce invasions, policies are needed at the international, national, and regional levels, yet most management actions (with some notable exceptions, examples of which are given below) necessarily occur at the local level, where custodianship, ownership, and governance to protect ecosystems may be the strongest. This disconnect makes coherent and enforceable policies across scales and jurisdictions complicated. Shifting governance and political trends also complicate designing and implementing global strategies. For example, some countries like the United States have recently taken steps backward in terms of national and coordinated international strategies in preventing and managing invasions (Meyerson et al. 2019). It is increasingly clear that effective

prevention and management of biological invasions requires a global governance approach, i.e., global-level leadership and coordination, which is prioritized by national governments from all countries with opportunities for different levels of buy-in depending on the capacities of the nation state.

The aim of this chapter is to highlight the need for global strategies to improve knowledge for the prediction, prevention, and management of IAS by coordinated efforts globally. While this book primarily focuses on plant invasions, the strategies discussed here apply not only to invasive plants but to all invasive taxa. We recognize that some specific strategies might need to be tailored to particular taxa. In a recent paper, Packer et al. (2017) advocated for global-scale research networks as an approach to address the intractable and large-scale questions related to biogeography that are fundamental to deepening our insights in invasion science. Here, we focus on policy and resulting management tools as a path toward effective coordinated strategies, including regulatory frameworks that combine incentive and compliance to address the increasing threats to biodiversity and ecosystem services posed by invasive species. We review major existing global research, policy, and management approaches to invasions, describe existing networks that use global or multiscale tools to better address invasions, and outline essential elements for global strategies to improve prevention and management of biological invasions.

16.2 What Are Global Strategies?

Although the need for global approaches to manage biological invasions is well recognized in invasion science – and already featured in some international legislations – achieving effective global strategies remains elusive. Globally oriented networks (Table 16.1) exist for knowledge generation (e.g., Kueffer et al. 2014; Packer et al. 2017), knowledge management (e.g., database curation, Environmental Impact Classification for Alien Taxa (EICAT)/Socio-Economic Impact Classification for Alien Taxa (SEICAT) risk assessments), and voluntary engagement in global policy guidelines (e.g., ISSG, Tables 16.2 and 16.3). However, no binding global strategy for the management of IAS has previously been

Table 16.2 Existing intergovernmental and international organizations with an IAS focus

Acronym	Full name	Stated purpose	Temporal scale	URL
IPBES	Intergovernmental science-policy platform on biodiversity and ecosystem services	To strengthen science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being, and sustainable development. From 2019 to 2023, IPBES is developing the global thematic assessment of invasive alien species and their control	8 years (2012–ongoing)	ipbes.net/
ISSG	IUCN invasive species specialist group-ISSG	Global network of scientific and policy experts on invasive species, organized under the auspices of the species survival commission (SSC) of the International Union for Conservation of nature (IUCN)	26 years (1994–ongoing)	issg.org/
OIE	World Organization for Animal Health	Intergovernmental organization responsible for improving animal health worldwide. The need to fight animal diseases at global level led to the creation of the Office International des Epizooties (OIE) through the international agreement signed on January 25, 1924. In 2003, the Office became the World Organization for Animal Health but kept its historical acronym OIE	96 years (1924–ongoing)	oie.int/

Table 16.3 Current international agreements related to invasive species prevention and management

Acronym	Convention/Treaty (if applicable)	Full name under convention or treaty	Description	Level of influence	No. of Parties
BWM	International convention for the control and Management of Ship's ballast water and sediments		Aims to prevent spread of harmful aquatic organisms from one region to another, by establishing standards and procedures for the management and control of ships' ballast water and sediments (2004) www.io.org/ www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships'-Ballast-Water-and-Sediments-(BWM).aspx	Legally binding (standard, record book, and certification)	8 signatory bodies and 81 contracting states
CBD	Convention on biological diversity	Article 8(h)	The CBD and its members recognize that there is an urgent need to address the impact of invasive alien species. Article 8(h) of the CBD states that "each contracting party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species." the CBD sets global priorities and guidelines, collects information, and helps to coordinate international action on invasive alien species The website also provides further information on invasive species and relevant decisions of the conference of the parties to the CBD www.cbd.int/convention/articles/default.shtml?a=cbd-08 www.fao.org/3/y5968e/y5968e0x.htm www.cbd.int/convention/articles/default.shtml?a=cbd-08	Legally binding	196
		Aichi target 9	Aichi target 9 By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment www.cbd.int/sp/targets/rationale/target-9/		
CBD	Convention on biological diversity	Conference of parties (COP)	Alien species that threaten ecosystems, habitats, and species (CBD COP 6 Decision VI/23, April 2002) to which are annexed the Guiding Principles for the Prevention, Introduction and Mitigation of Impacts of Alien Species that threaten Ecosystems, Habitats or Species www.cbd.int/decision/cop/?id=7197 www.cbd.int/doc/decisions/cop-06-dec-23-en.pdf		
CITES	Convention on international trade in endangered species of wild Flora and Fauna		Multilateral treaty to protect endangered plants and animals. It was drafted as a result of a resolution adopted in 1963 at a meeting of members of the International Union for Conservation of nature. The convention was opened for signature in 1973 and CITES entered into force on July 1, 1975 cites.org/	Legally binding (licensing system)	183

CMS	Convention on migratory species of wild animals		Environmental treaty under the aegis of United Nations environment Programme, global platform for conservation and sustainable use of migratory animals and their habitats. CMS brings together the states through which migratory animals pass, the range states, and lays the legal foundation for internationally coordinated conservation measures throughout a migratory range. CMS is also known as the Bonn convention cms.int/	Legally-binding (framework)	128
IHR (2005)		International Health Regulations (1969)	The International Health Regulations (2005) are an international law which helps countries work together to save lives and livelihoods caused by the international spread of diseases and other health risks. They entered into force on June 15, 2007 and are binding on 194 countries across the globe, including all WHO Member States. The IHR (2005) aim to prevent, protect against, control, and respond to the international spread of disease while avoiding unnecessary interference with international traffic and trade. The IHR (2005) are also designed to reduce the risk of disease spread at international airports, ports, and ground crossings who.int/	Legally binding	Not stated
IPPC	International plant protection convention		The international plant protection convention (IPPC) is a legally binding treaty on plant health administered by the food and agriculture organization (FAO) but implemented through the cooperation of member governments and regional plant protection organizations. The goal of the IPPC is to coordinate work to prevent the spread and introduction of pests of plants and plant products and to promote appropriate measures for their control, with minimal disruption to trade. The IPPC develops international standards for phytosanitary measures (ISPMs) ippc.int/	Legally binding (framework)	183
Ramsar	Ramsar convention on wetlands of international importance especially as waterfowl habitat		An international treaty for the conservation and sustainable use of wetlands. It is also known as the convention on wetlands. It is named after the city of Ramsar in Iran, where the convention was signed in 1971 ramsar.org/	Legally binding	170

(continued)

Table 16.3 (continued)

Acronym	Convention/Treaty (if applicable)	Full name under convention or treaty	Description	Level of influence	No. of Parties
UNCLOS	United Nations convention on the law of the sea		An international treaty adopted and signed in 1982 and replacing the four Geneva Conventions of April, 1958, which respectively concerned the territorial sea and the contiguous zone, the continental shelf, the high seas, fishing, and conservation of living resources on the high seas. The Convention has created three new institutions: the International Tribunal for the Law of the Sea, the International Seabed Authority, and the Commission on the Limits of the Continental Shelf. The Convention has become the legal framework for marine and maritime activities, and IUCN and its partners are working toward an implementing agreement (UNCLOS IA) that will close important gaps in governance. A positive result would provide a measure of protection and conservation of Areas Beyond National Jurisdiction (ABNJ) where there is none at present www.un.org/Depts/los/convention_agreements/convention_overview_convention.htmtreaties.un.org/Pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XXI-6&chapter=21&Temp=mtdsg3&clang=_en	Legally binding	157
UN SDGs	The sustainable development goals report	15.8 prevent invasive alien species on land and water ecosystems	The 2030 Agenda for Sustainable Development was launched in 2015 to end poverty and set the world on a path of peace, prosperity, and opportunity for all on a healthy planet. The 17 Sustainable Development Goals (SDGs) demand nothing short of a transformation of the financial, economic, and political systems that govern societies today to guarantee the human rights of all. They require immense political will and ambitious action by all stakeholders unstats.un.org/sdgs/	Non-legally binding	193

UN watercourses convention	Convention on the law of non-navigational uses of international watercourses		International treaty, adopted by the United Nations in 1997, pertaining to the uses and conservation of all waters that cross international boundaries, including both surface and groundwater. The UN drafted the document to help conserve and manage water resources for present and future generations. From the time of its drafting, the convention took more than 17 years to enter into force on august 17, 2014. with the treaty having been ratified by just 36 states, the majority of countries remain outside its scope. The convention, however, is regarded as an important step in establishing international law governing water treaties.un.org treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-12&chapter=27&lang=en	Legally binding	39
WTO	The World Trade Organization	SPS agreement - agreement on the application of sanitary and phytosanitary measures	The WTO agreement on the application of sanitary and phytosanitary measures (SPS agreement). The agreement entered into force with the establishment of the World Trade Organization on January 1, 1995. It concerns the application of food safety and animal and plant health regulations. The SPS agreement is administered by the committee on sanitary and phytosanitary measures (the "SPS Committee"), in which all WTO members can participate wto.org/ www.wto.org/english/tratop_e/sps_e/spsund_e.htm	Encourages governments to establish own regulations based on international standards	Not stated

Note: International agreements may range from legally binding treaties (called Agreements) to less formal instruments, such as Memoranda of Understanding (https://www.cms.int/en/legalinstrument/cms)

proposed. International cooperation does exist for some circumstances where management can have international implications. For example, because introduced biological control organisms do not respect political boundaries, the Technical Advisory Group for Biological Control Agents of Weeds was formed in North America. This group advises the US Department of Agriculture Animal and Plant Health Inspection Service and has members from the United States, Canada, and Mexico (USDA APHIS, accessed 23 July 2020). However, such groups are the exception rather than the norm.

To illuminate the gap between the existing and recommended approaches, here we define the characteristics of global strategies within invasion science. While *global networks* focus on building evidenced-based knowledge and management, *global strategies* focus on evidence-based vision and policy, as well as management. Addressing the challenges of IAS requires globally integrated approaches to predict, prevent, and manage IAS, with considerations of the level of development and capacity of individual nations (Latombe et al. 2017). Therefore, an effective global strategy for biological invasions must be both locally relevant and identify the relationships between the global and local causes and impacts of IAS to economic, social, environmental, public health, and political outcomes. Below, we provide examples of past and extant global organizations and strategies (Table 16.2) that focus on IAS.

Building on the criteria for global networks (Packer et al. 2017), we define global strategies as frameworks for evidence-based visions, policy agreements, and commitments that coordinate multinational efforts to address the patterns, mechanisms, and impacts of biological invasions. Although advanced by global cooperation, the criteria for such strategies may be implemented at the global (e.g., requirements for treatment of ballast water along shipping routes, funding for data collection networks), as well as at continental or finer scales where they can be best addressed by multiple regions yet benefit all nation states (e.g., phytosanitary agreements). Therefore, a workable global strategy needs to be modular – i.e., must have components that countries can buy into or not, depending on the availability of resources and political will. It is obvious that not all countries can or will opt for the comprehensive model with all recommended components, thus requiring a "hierarchy of strategies" model to maximize inclusion. Consequently, effective global strategies against biological invasions must include the following:

(i) Address biological invasions at the global scale through a biogeographic lens of nation states.
(ii) Consider legally binding regulatory frameworks, which may include optional self-regulatory or voluntary components, to address shared global priorities.
(iii) Coordinate data management to ensure harmonization of data captured at different locations and of rigorous data analysis.
(iv) Build, monitor, and maintain long-term collaborations and trust between member states and their representatives, including a shared understanding of an agreed, but realistic, action timeframe to target complex IAS dynamics.

16.2.1 A Brief Overview of Global Initiatives on Biological Invasions

Efforts to prevent and manage IAS have been developed at the global scale over the past 30 years (Foxcroft et al. 2017). In recognition of the growing number of species transported across geographic barriers and the related major risks and negative impacts, a global assessment of biological invasions was organized by the Scientific Committee on Problems of the Environment (SCOPE), a body of the International Council of Scientific Unions. This 3-year program attempted to draw some generalities by focusing on a number of key questions that invasion scientists still wrestle with today: (i) What are the characteristics of a successful invader? (ii) What characteristics determine the susceptibility to invasion? (iii) How successful are attempts to predict the outcome of an introduction? (iv) How should knowledge be used to manage invaded ecosystems?

The Invasive Species Specialist Group (ISSG) of the IUCN Species Survival Commission (SSC) is a global network of science and policy experts on invasive species, organized under the auspices of the Species Survival Commission (SSC) of the International Union for Conservation of Nature (IUCN). The ISSG was established in 1994 and currently has 196 core members from over 40 countries and a wide informal global network of over 2000 conservation practitioners and experts, who contribute to its work. The overall aim is to highlight and mainstream invasive species issues, such that they are addressed in an ecosystem context. Activities include providing technical and scientific advice to IUCN members in their work on invasive species, especially in international fora (e.g., Convention on Biological Diversity, CBD; the Ramsar Convention on Wetlands; International Maritime Organization, IMO), and work in the regions. The ISSG membership also provides technical and scientific advice to national and regional agencies in developing policies and strategies to manage the risk of biological invasions (Table 16.2).

The Global Invasive Species Programme (GISP) was initially developed in January 1996 and established in 1997 to address the global threats caused by IAS and to provide support to the implementation of Article 8(h) of the Convention on Biological Diversity. It was coordinated by the Scientific Committee on Problems of the Environment (SCOPE), in collaboration with the World Conservation Union (IUCN), and the Centre for Agriculture and Bioscience International (CABI). Participating groups and individuals made substantial in-kind contributions (McNeely et al. 2001). GISP contributed extensively to the knowledge and awareness of invasive species and developed a guide, *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices*, to address the problem and a *Global Strategy on Invasive Alien Species* composed of ten strategic responses to address the problem of IAS (Box 16.2).

Most recently established, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assesses the state of biodiversity and the ecosystem services provided to society in response to requests from decision-makers (Díaz et al. 2015a, Table 16.2). IPBES has defined five major drivers of biodiversity decline at a global scale: land-use change, direct use, pollution, climate change, and invasive species (Brondizio et al. 2019). For invasive species, since 2019, IPBES is carrying out a thematic global assessment with the specific objective, "To assess the threat that invasive alien species pose to biodiversity, ecosystem services and livelihoods and the global status of and trends in impacts of invasive alien species by region and sub-region, taking into account various knowledge and value systems" (IPBES 2018). With 87 experts from 46 countries, as of August 2020, this assessment is anticipated to bring together the latest comprehensive state-of-the-art knowledge on invasive species and the strategies to control them at local and global scales and

Box 16.2 Ten strategic responses recommended in the GISP 2001 *Global Strategy on Invasive Alien Species* (http://www.issg.org/pdf/publications/GISP/Resources/McNeeley-etal-EN.pdf) along with the theme of the proposed strategy that it addresses most directly indicated in parentheses

1. Build management capacity (capacity).
2. Build research capacity (capacity).
3. Promote sharing of information (prevention).
4. Develop economic policies and tools (prevention).
5. Strengthen national, regional, and international legal and institutional frameworks (prevention and management).
6. Institute a system of environmental risk analysis (prevention).
7. Build public awareness and engagement (prevention).
8. Prepare national strategies and plans (management).
9. Build invasive alien species issues into global change initiatives (management).
10. Promote international cooperation (capacity).

is expected to be approved by the intergovernmental plenary at the Plenary's tenth session (IPBES-10), in May 2023. A key element of this assessment is that all evidence should be informative for global and national policy-making. Therefore, the assessment considers not only biological evidence but also economic and social aspects that are critical for building effective conservation strategies.

These global initiatives are complemented with numerous regional, national, and thematic approaches (e.g., related to particular biomes, organism groups, or introduction pathways, McDougall et al. 2011; Wilson et al. 2011; Brunel et al. 2013) and voluntary approaches (discussed in the following paragraph). For example, in South Africa, there is a high level of awareness on issues related to invasions, and the recently approved strategy to manage biological invasions is supported by national legislation and government-level funding. South Africa has adopted a diversified approach to managing invasive species, including employment creation and ecological restoration. While recognizing that eradication is not feasible for most invasive species, South Africa seeks to minimize the impacts of invaders at the lowest possible cost and in as many locations as possible in perpetuity (van Wilgen 2018).

A mix of legally binding and voluntary approaches is highly likely to produce the most effective global strategies for the prevention and management of IAS. Therefore, equally important to successful global strategies are voluntary "codes of conduct," standards, and certification schemes (such as for forests), which set practices to prevent, restrict, or exclude the use of IAS. For example, Brundu and Richardson (2016) and Brundu et al. (2020) proposed a voluntary code of conduct and global guidelines for planted forest and non-native trees which complement similar codes for planted forest, botanical gardens, and ornamental horticulture. The code for planted forests is comprised of 14 principles and is relevant to all stakeholders and decision-makers in the 47 member states in the Council of Europe (Brundu and Richardson 2016). Forest certification standards, such as those of the Forest Stewardship Council (https://fsc.org/en) and PEFC (Programme for the Endorsement of Forest Certification schemes), regulate the use of alien trees to prevent invasions outside of plantations by straddling voluntary and legally binding approaches. Another relevant example is ISPM 41 (FAO 2017), i.e., the International Standard for Phytosanitary Measures which identifies and categorizes the risk associated with the international movement of used vehicles, machinery, and equipment utilized in agriculture, forestry, horticulture, earth moving, surface mining, waste management, and the military. The standards identify appropriate phytosanitary measures to reduce the accidental spread of pests, including invasive alien species.

In addition to global strategies, disciplinary or thematic research networks have changed the ways in which we understand and address invasions, including the invasibility of specific ecosystem types (e.g., Mountain Invasion Research Network, Alexander et al. 2016, International Council for the Exploration of the Sea), deepening our understanding of the impacts resulting from invasions (e.g., Environmental Impact Classification of Alien Taxa, Hawkins et al. 2015), and curated data that enables these assessments (e.g., DAISIE, Hulme et al. 2009; GloNAF, Pyšek et al. 2017; van Kleunen et al. 2019). Complementing these knowledge networks are policy-oriented collaborations (e.g., IUCN, ISSG) that provide guidance for regional (e.g., European Union) and state (e.g., Australia) mechanisms to address the risks associated with the introduction of alien species (e.g., as pets, live bait, food, or unintended stowaways (UNEP 2016) and impacts where alien species establish and become invasive. Despite the concerted efforts of many networks and important progress on developing evidence-based policy, current knowledge and policy have failed to halt the escalating spread and impact of invasive organisms. More effective coordination and interventions (e.g., Waage and Reaser 2001; Kumschick et al. 2017) that require less reliance on voluntary goodwill and a more mandated systemic and legislative approach (Banks et al. 2015) are needed. The greatest challenges are identifying and negotiating the remaining knowledge, policy, and drivers (e.g., incentives) to increase proactive prevention that benefits all states and to achieve binding strategies where appropriate, or voluntary actions.

16.2.2 Key Elements of Global Strategies and Main Planning Tools

The science and techniques of strategic planning have an extensive history that includes multiple and competing theories to explain the strategic planning process and its relationship to formulating and achieving management objectives (Papke-Shields and Boyer-Wright 2017). In this section, we review some of the key elements for successful strategies, including strategic planning, scenario planning, strategic management, and execution of global strategies for better prevention and management of IAS, with a special focus on the application of these elements in the field of invasion science.

Strategic planning has a visionary component, but care must be exercised to ensure that all objectives are specific, measurable, action-oriented, realistic, and time-bound (SMART, McDermott et al. 1999). For example, the vision statement of the Australia Weed Strategy 2017–2027 aims to "Protect Australia's economic, environmental and social assets from the impacts of weeds." A strengths, weaknesses, opportunities, and threats (SWOT) analysis, or SWOT matrix, is a model used at the beginning of an organization's strategic planning. Strengths and weaknesses are considered internal factors, while opportunities and threats are considered external factors. Genovesi et al. (2010) identified five distinct options for a European Early Warning and Rapid Response (EWRR) system (i.e., voluntary network of national authorities, non-institutional panel, intergovernmental coordinating body, intergovernmental agency, intergovernmental central authority). In their report, a concise description of the organizational model for each of the options was presented, along with a SWOT analysis to facilitate evaluation of the alternatives. At a local scale, Mukwada and Manatsa (2017) carried out a SWOT analysis of the policy framework guiding the control of the invasion of the Australian tree *Acacia mearnsii* and other IAS in the Golden Gate Highlands National Park in South Africa. The implementation of restoration measures in the park and adjacent communities was in line with the recommendations of the Convention on Biodiversity. They identified the need to strengthen relationships with the community in the park, improve legislation, and boost the technical capacity of parks in South Africa to manage IAS. Following such an analysis, a *strategy map* is a useful tool for strategic planning, especially at the global level. A strategy map is a visual tool designed to clearly communicate a strategic plan and achieve the desired goals. Strategy mapping should be a major part of any strategic document that offers an excellent way to communicate the knowledge across the committed organization(s) and the stakeholders in an easy-to-follow format.

Scenario planning is a management tool that originated in the trade and business world that enables executives to develop strategies in uncertain business environments (Oliver and Parrett 2018). More recently, this tool has been applied by Yemshanov et al. (2017) to the invasion of the Asian long-horned beetle (*Anoplophora glabripennis*) in Ontario, Canada. They proposed a scenario optimization model that incorporates uncertainty about the spread of an invasive species and allocates survey and eradication measures to minimize the number of infested, or potentially infested, host plants on the landscape. Booy et al. (2020) assessed the possibility of eradicating dozens of established but not yet invasive species in the EU and found that eradication feasibility and risk scores were not correlated, suggesting each approach uses distinct criteria. Using a horizon scan, they further identified more than two dozen new species that are priorities for immediate or high-priority eradication.

Strategy review and refinement is necessary to ensure that the right course of action is being taken. For example, the Phytosanitary Capacity Evaluation (PCE) is a diagnostic tool enabling countries to assess the weaknesses and strengths of phytosanitary systems in relation to their ability to fully implement the International Plant Protection Convention (IPPC, Table 16.3) and other international phytosanitary obligations and standards. The PCE has also been applied as a cross-disciplinary tool among the sanitary, phytosanitary, and food safety areas in the Andean subregion in South America. Since IAS are often a significant subset of "quarantine pests," as defined

by the IPPC, PCE results are already useful in relation to invasive species. The PCE methodology has the potential to be further developed to cover a country's needs in implementing Article 8(h) of the Convention on Biological Diversity (CBD, Table 16.3, discussed below in Sect. 16.2.3). Through its integration at the global scale with existing international IAS and mountain networks such as the Global Mountain Biodiversity Assessment (GMBA) and Mountain Research Initiative (MRI), the CBD reaches out to the broader research and management communities. This approach has helped to improve management strategies specific to mountains (Kueffer et al. 2013a), enlarged the databases on alien and invasive plants at high elevations, and furthered the understanding of the specific processes driving plant invasions in mountains (Kueffer et al. 2013a). The example of mountain invasions (Box 16.3) that were long neglected in the global science and

Box 16.3 The Mountain Invasion Research Network (MIREN)

The Mountain Invasion Research Network (MIREN, www.mountaininvasions.org) has over 15 years of experience in bringing together academic and nonacademic expert groups (invasion and mountain scientists, managers) to understand biological invasion processes and support management actions to prevent and control IAS in mountains. The scientific aim of MIREN is to understand the effects of global change on species' distributions and biodiversity in mountainous areas. While the initial focus was on non-native plant invasions, it now considers more generally species redistribution along elevational gradients under different drivers of global change, including climate and land-use change. The network uses observational and experimental studies along elevation gradients across multiple sites at all latitudes worldwide to evaluate and quantify the processes and mechanisms that are shaping mountain plant communities at regional to global scales. MIREN includes over 20 sites on all continents, except Antarctica. Its taxonomic focus has been mainly in plants, but its experience is useful for any taxa.

Four elements of the MIREN approach can be useful for designing similar networks focused on other invasions (e.g., in particular habitat types, for specific taxonomic groups, or in association with certain invasion pathways such as horticulture or forestry), (adapted from Kueffer et al. 2014):

1. **Global network with local support:** MIREN is a multiscale network that links local scales with the global scale by integrating a global network of local case studies into existing international invasive species and mountain networks. A bottom-up structure with two elected co-chairs from different case study regions has helped to maintain the network dynamics.
2. **Inter- and transdisciplinary work:** MIREN links two interdisciplinary fields of expertise on invasive species and mountains with local practitioners and stakeholders.
3. **Non-centralized funding:** MIREN has never been centrally funded by one large grant; rather, it is the collective effort of local grants that support the networks' activities. This increases flexibility and long-term sustainability that are often lacking in the case of single-grant funding.
4. **Adaptive research:** The observational and experimental research that MIREN uses across all sites is tightly linked to the experience of local managers. The scientific goals and methods are discussed across academic and nonacademic MIREN members from all regions. This ensures that research approaches can be regularly adapted to emerging management needs or new scientific questions in the different world regions.

management community shows how important it is to tailor global strategies to particular ecological contexts (such as mountain environments) and ensure a bottom-up process (Kueffer et al. 2013b).

Strategic management is usually defined as the comprehensive collection of ongoing activities and processes that organizations use to systematically coordinate and align resources and actions with mission, vision, and strategy (Strickland and Thompson 1995; Pressey et al. 2013). Strategic management activities transform the static strategic plan into a system that provides strategic performance feedback to decision-making and enables the plan to evolve and grow as requirements and circumstances change.

Strategy execution is basically synonymous with strategy management and amounts to the systematic implementation of a plan of action. Both the "planning" or rational method and the "learning" or adaptive method could be applied to strategy drafting and strategic management for IAS. In practice, however, the demarcation between planning and learning approaches has become more and more blurred, and a major problem in IAS management is uncertainty (Latombe et al. 2017; Robertson et al. 2020). Managers can be faced with at least four (Latombe et al. 2019) main types of uncertainty: (1) to clearly circumscribe the invasion phenomenon, (2) to measure and provide evidence for the phenomenon (i.e., confirmation), (3) to understand the mechanisms that enable the phenomenon, and (4) to understand the mechanisms through which the phenomenon results in consequences. Active adaptive management (AAM) is a deliberate plan for learning about the managed system, which can be improved in the face of uncertainty. For example, the potential benefits of applying AAM has been identified for insect pest and weed control (Shea et al. 2002).

A key stage in strategy building is engagement with actors to achieve ownership of strategies, a supportive institutional framework, and the ability to continuously learn and adapt (Novoa et al. 2018; Shackleton et al. 2019a). Given the hybrid local and global nature of the invasive species phenomenon, strategies must be locally rooted but globally connected. The Mountain Invasion Research Network (MIREN, Table 16.1) is an example of a global invasive species network that enables a transdisciplinary, multiscale learning process at the science-policy interface (Kueffer et al. 2013a). MIREN encompasses about 20 case study sites carefully selected from different ecological (subarctic to tropical, continents, and islands) and socioeconomic contexts (developing and developed countries), including both research and management institutions at the sites (Box 16.3). It aims to strengthen anticipatory research and precautionary management through replicated local case studies and cross-site learning; in other words, it creates globally distributed local communities of practice. In summary, "MIREN has established a 'community of practice,' including experts from both academia and management institutions, that is global but locally-rooted and capable of addressing diverse multi-scale global change problems in mountains" (Kueffer et al. 2014).

16.2.3 Existing Legislation Supportive of Invasive Species Global Strategies and International Cooperation

A myriad of organizations, with diverse mandates and residing in a wide range of government departments, support global strategies on invasive species prevention and management (Table 16.3). For example, since 1992, the Convention on Biological Diversity (CBD 1993) has identified IAS as a major cross-cutting theme. This global treaty requires Parties "*as far as possible and as appropriate*, (to) prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" [Article 8(h)]. In 2002, the CBD Conference of the Parties (COP) adopted specific decision and guiding principles to help parties implement this policy instrument. The 2002 decision urges parties, other governments, and relevant organizations to prioritize the development of IAS strategies and action plans at national and regional level and to promote and implement the CBD Guiding Principles.

In addition to the CBD, the SPS (Sanitary and Phytosanitary Measures) Agreement, standards of the IPPC and OIE (World Organization for Animal Health, formerly the Office International des Epizooties), and several other international regulations and conventions – particularly the Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES), the International Ballast Water Management Convention, the Bern Convention, the Ramsar Convention, and the International Health Regulations – are relevant for different aspects of IAS and represent an important legal foundation for any global strategy on biological invasions. Similarly, a large number of international and nonprofit organizations are involved in efforts focused on raising awareness, prevention, monitoring, control, and/or eradication of invasive species, including capacity building and strategic planning or management. Several nations have developed recommendations or guidance on pest and animal movements related to invasions. While some of this work is binding on countries, much is voluntary or can be classified in the more general category of "soft law." The number of conventions and organizations that are relevant to prevention, control, and eradication underpins both the importance and challenge of ensuring synergies and coherence in order to avoid overlaps and gaps. In fact, the Inter-Agency Liaison Group on Invasive Alien Species was established to facilitate such cooperation (www.cbd.int/invasive). Besides the need for effective interagency and interdisciplinary cooperation at the global level, collaboration is essential among national authorities responsible for different aspects of IAS (WTO 2013).

Measures to prevent the introduction or limit the spread of IAS may, by their nature, be trade restrictive. Close alignment between the CBD and the WTO SPS Agreement, as well as among other relevant international organizations, is therefore beneficial to help achieve the objectives of these instruments without restricting trade (Lopian 2005). The relationship between international trade and IAS was the focus of a seminar organized by the Standards and Trade Development Facility (STDF), in collaboration with the IPPC, the OIE, and the WTO, in July 2012. The seminar was successful in raising awareness about the mutually beneficial goals of the CBD and the SPS Agreement and the contribution of the two relevant standard-setting organizations (IPPC, OIE) under the SPS Agreement (WTO 2013).

16.3 Responding to Novel Threats: Further Developing Global Networks and Knowledge Systems to Support Global Strategies

Newly emerging opportunities for the introduction of organisms to the non-native regions, associated with the opening of new pathways (Hughes et al. 2020), require improved knowledge systems and tools that would allow dealing with these fresh invasions. In this section, we present examples of such new pathways (emerging trade, including e-commerce, and increasing travel routes) and describe approaches (common garden experiments) and tools (databases) for improving our knowledge base (focused research involving novel species, novel technologies, and tools) that can be used to design novel strategies on IAS.

16.3.1 Global Data Registries, Data Harmonization, and Standardization

Resourcing and rewarding global registries for data collection and research on invasions are avenues to support global strategies that focus on policy and management. Nations could manage global coordination through memoranda of understanding (MOUs). Table 16.4 provides examples and descriptions of databases and data repositories that cover large spatial scales (in some cases, global) that have advanced invasion research, management, and policy. Nonetheless, significant gaps in geographic, pathways' relationship, and taxonomic coverage persist. Increasingly, databases are paying attention to biases and gaps in the distribution of data. Data gathering efforts

Table 16.4 Examples of databases and repositories that focus on invasive species or include data relevant to biological invasions

Acronym	Full name	Description	URL
Alien floras and faunas	Series in the journal *Biological Invasions* on alien floras and faunas	Alien floras and faunas includes papers and data that provide information on complete alien floras or faunas of large regions, such as countries, with clearly described criteria used to assess the species' status as casual, naturalized, or invasive. Full species lists with relevant available information must be published with the paper as electronic supplementary material	Pyšek et al. (2018)
BISON	Biodiversity information serving our nation	Web-based federal mapping resource for species occurrence data in the United States and its territories. Researchers collect species occurrence data, records of an organism at a particular time in a particular place	bison.usgs.gov/#home
CABI	CABI invasive species compendium	The invasive species compendium (ISC) is an encyclopedic resource that brings together a wide range of different types of science-based information to support decision-making in invasive species management worldwide. The US Department of Agriculture is a lead partner with CABI in the development of this compendium which has been resourced by a diverse international consortium of government departments, non-governmental organizations, and private companies. The horizon scanning tool is a decision support aid that helps you identify and categorize species that might enter a particular geographic area from another geographic area	www.cabi.org/ISC www.cabi.org/horizonscanningtool
DAISIE	Delivering alien invasive species inventories for Europe	A structured inventory of invasive species that threatens European terrestrial, freshwater, and marine environments to provide the basis for prevention and control, to assess and summarize the ecological, economic, and health risks and impacts for early warning	www.europe-aliens.org/
EPPO GDB	European and Mediterranean Plant Protection Organization Global Data Base	The EPPO global database is maintained by the secretariat of the European and Mediterranean Plant Protection Organization. The aim of the database is to provide all pest-specific information that has been produced or collected by EPPO. The database contents are constantly being updated by the EPPO secretariat. It holds basic information for more than 88,000 species of interest to agriculture, forestry, and plant protection	gd.eppo.int/
GLONAF	Global naturalized alien Flora	A living database on alien plants that is both research and policy relevant	van Kleunen et al. (2019)
GLOPNET	Global plant trait network	A research collaborative that studies and compiles data on plant traits in order to synthesize existing data to answer new questions and encourage further study on plant traits	bio.mq.edu.au/~iwright/glopian.htm

(continued)

Table 16.4 (continued)

Acronym	Full name	Description	URL
GRIIS	Global register of introduced and invasive species	The global register of introduced and invasive species provides country-wise checklists of introduced and invasive species. GRIIS was conceived to provide a sustainable platform for information delivery to support national governments. In the future, it aims to enable a global system for sustainable monitoring of trends in biological invasions that affect the environment	Pagad et al. (2018); https://doi.org/10.1038/sdata.2017.202
iNaturalist		One of the world's most popular nature apps, which helps to identify and map plants and animals, and to get connected with a community of over a million scientists and naturalists.	Spear et al. (2017); https://doi.org/10.3389/fevo.2017.00086
INVASIVESNET	International Association for Open Knowledge on invasive alien species	This association facilitates greater understanding and improved management of IAS and biological invasions globally by developing a sustainable network of networks for effective knowledge exchange	www.invasivesnet.org/
Kew genome size database	Plant DNA C-values database	The plant DNA C-values database currently contains C-value data for 12,273 species	cvalues.science.kew.org/
PREDICTS		As of August 2020, the PREDICTS database has >3.6 million biodiversity records from over 32,000 sites, covering more than 50,000 species. Database could be used to answer questions such as "Do changes in land-use facilitate success of invasive species?"	www.predicts.org.uk Hudson et al. (2016); https://doi.org/10.1002/ece3.2579
TRY	Plant trait database	A global database of curated plant traits	www.try-db.org/de/Datasets.php

across geographic regions and taxonomic groups are key to addressing the problems invasive species pose (e.g., van Kleunen et al. 2015), and including new datasets, e.g., including iNaturalist data in IAS assessments, could be fruitful.

Bigger datasets could result in higher bias, so careful selection of data and appropriate statistical design should be ensured in order to limit correlated errors when handling big datasets (Deriu et al. 2017; Groom et al. 2017; Wang et al. 2018). Reducing barriers to data sharing and interoperability will significantly improve our ability to respond as quickly as possible to the challenges of biological invasions as trading partners and trade pathways shift and as global change brings new invasive species challenges to the fore.

16.3.2 Model Species

One way in which researchers have sought to better understand invasions and to gain insights for improved predictions is by adopting a model approach with a single species. Model organisms are a limited suite of species used to understand generalities among a larger group of organisms and can save time and resources in research. Kueffer et al. (2013b) suggested that model systems could help address "wicked" (*sensu* Woodford et al. 2016) questions in invasion science, including those at the global scale. Research that employs an appropriate model organism may help to identify mechanisms and processes underlying invasions and allow researchers to more rapidly test hypotheses and advance empirical invasion science. Developing model systems in invasion science is increasingly possible due to recent curation of comprehensive datasets (Table 16.4) and formation of both public and private collaborative research consortia (Table 16.1). Examples of model species in invasion science include the cosmopolitan grass *Phragmites australis* (Meyerson et al. 2016), the lady bird beetle *Harmonia axyridis* (Roy and Wajnberg 2008), and many others (e.g., Kueffer et al. 2013b; Novoa et al. 2020). The identification of appropriate model species in invasion science with open-access data registries not only could catapult research globally but also serves as a powerful tool for policy development, where model species provide both cautionary tales and lessons learned for prevention and management.

16.3.3 Technologies and Tools to Develop Successful Global Strategies

Inexpensive and transferrable technologies – both low and high end – that can be easily shared and used around the world are needed to support global strategies to prevent and manage invasive species. For example, prior to import, relatively inexpensive diagnostic technologies such as flow cytometry can be used to quickly assess plant ploidy level and genome size – both correlates of plant invasiveness (te Beest et al. 2012; Pandit et al. 2014; Suda et al. 2015). Global citizen science platforms like iNaturalist (https://www.inaturalist.org/; Spear et al. 2017), and groups like the Conservation X lab (conservationx.com/challenge/invasives/zero), are challenging and inspiring people to ideate and develop innovative solutions to existing roadblocks in invasive species detection. People all over the world are stepping up to meet this challenge through the development of technologies like smartphone apps or identifying low-tech ways to solve "wicked problems." Table 16.5 summarizes some of the technologies that are currently being used or are at developmental stage to manage IAS globally. As old technologies advance and newer ones emerge globally, and as cross-disciplinary collaborations grow, possibilities exist for their applications and the development of novel tools for global IAS strategies.

16.4 Concluding Remarks

While IAS challenges are global, the nature and severity of their impacts on biodiversity, economies, health, and society are unevenly distributed across nations and regions. Thus, some aspects of the problem require local or regional solutions tailored to the specific values, needs, and priorities of states or regions (e.g., islands, protected areas, local authorities, indigenous communities), while others call for consolidated action by the larger global community. Certainly, any global strategy

Table 16.5 Examples of available and readily transferable technologies that can be used to manage invaders in multiple regions or countries. The policies associated with the use of these technologies could be negotiated through shared governance processes

Technology	Description	Examples and applications	References
eDNA	Environmental DNA (eDNA) is the genetic material from a plant or animal that is found in the air, water, or soil or other substrata. It has recently emerged as a powerful genetic tool for detecting invasive species and rare aquatic organisms. This technology involves detection of DNA in an environmental sample, such as lake or river water	Fish, such as Asian carp, release DNA into the environment in the form of skin cells, secretions, and feces. This DNA can be collected from water samples in the field and be used to indicate the potential presence of an individual species. Zaiko et al. (2018) review the merits and limitations of this technology	Asiancarp.Us/eDNA.Html Egan et al. (2013); https://doi.org/10.1111/conl.12017 Zaiko et al. (2018); https://doi.org/10.3389/fmars.2018.00322 Ruppert et al. (2019); https://doi.org/10.1016/j.gecco.2019.e00547
Genome editing	Technique to insert, delete, or modify DNA to silence or activate specific genetic characteristics. The development of clustered regularly interspaced short palindromic repeats (CRISPR) combined with the Cas9 enzyme (CRISPR/Cas9) rapidly increased the specificity and efficiency of gene editing and decreased costs	Genome editing is currently being applied to human health and crop protection (e.g., vector-borne disease, crop pests). Potential future uses include invertebrate pests for sterile insect technique releases to cause mosquito eradication in Hawaii to eliminate avian malaria that is driving and inducing native species to be resistant to disease (e.g., bats for white-nose syndrome, amphibians for the fungal disease chytridiomycosis)	isac_advanced_biotechnology_white_paper.pdf Vasiliou et al. (2016); https://doi.org/10.1373/clinchem.2016.263186 Wang et al. (2016); https://doi.org/10.1146/annurev-biochem-060815-014607
Gene drives	Gene drives advance genome editing by introducing a mechanism that promotes the inheritance of a particular gene to increase its frequency in a population. The process "drives" the desired genetic trait through subsequent generations of offspring from the modified individual(s). Gene drives provide the potential to modify sexually reproducing wild populations by design	Gene drives allow specific genes to be inserted, modified, or deleted. They can be used to modify populations to no longer carry a disease or to alter the sex ratio of all offspring to all male. To date, CRISPR gene drives have been synthesized in yeast, fruit flies, and two species of mosquito (NAS 2016). Specific applications include mosquito control to limit the transmission of malaria and other vector-borne diseases, as well as possible use to eradicate invasive rodents on islands	(NISC) isac_advanced_biotechnology_white_paper.pdf
GIS	Geographic information systems are tools that allow users to create interactive queries, analyze spatial information, edit data in maps, and present the results of all these operations	In combination with remotely sensed data and geospatial data collected via field work or from existing available data, GIS can be used to map and analyze invasive species establishment and spread and relate environmental characteristics and anthropogenic effects to different invasion stages	Haltuch et al. (2000); https://doi.org/10.4319/lo.2000.45.8.1778

(continued)

Table 16.5 (continued)

Technology	Description	Examples and applications	References
Horizon scanning	Horizon scanning is defined as a systematic examination of potential threats and opportunities within a given context. Horizon scanning to prioritize the threat posed by potentially new IAS which are not yet established within a region is seen as an essential component of IAS management	The horizon scanning techniques has been applied in the European Union, in the United Kingdom, and in other countries and regions. Lists of species are usually generated by individual experts and collated within thematic groups in advance of the workshop. Scores for risk criteria, coupled with information on the level of confidence of the relevant scores, are applied to species and reviewed to allow collation into one consensus list for each thematic group. An expert workshop is subsequently used to build consensus to derive a single agreed list of priority species across all thematic groups while also reviewing the process that produced the lists	Roy et al. (2014); https://doi.org/10.1111/gcb.12603
Novel poisons	Delivery of nontraditional toxicant to control an invasive species	Acetaminophen hidden in mice that are air dropped into Guam. The snakes ingest the poisoned mice and die	nationalgeographic.com/news/2010/09/100924-science-animals-guam-brown-tree-snakes-mouse-tylenol/
Remote sensing	Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance	Using remote sensing technology, existing populations of invasive species can be identified (classified) and mapped using GIS LiDAR (light detection and ranging) in the form of a pulsed laser used to measure ranges (variable distances) to the earth is a particular kind of remote sensing. In Yellowstone National Park, USA, it can be used to locate and capture non-native fish during the brief weeks each year when they come into shallow water to spawn Google earth engine is a freeware available to download and process freely available satellite imagery	(USGS) pubs.usgs.gov/fs/2011/3109/FS11-3109.pdf Roddewig et al. (2018); https://earthengine.google.com/

RNAi	Ribonucleic acid interference (RNAi) "silences" targeted genes. By the introduction of double-stranded RNA into the cell, it destroys the single-stranded messenger RNA with the same sequence	Can be used to provide resistance to pests and diseases and eliminate production of specific hormones or can be a taxa-specific toxicant. Future uses for invasive species control could include taxa-specific hormone suppressants in baits that would disrupt social dynamics or turn workers against queens, leading to colony collapse in invasive social invertebrates like ants	Fire et al. (1998); https://doi.org/10.1038/35888 Heath et al. (2014); https://doi.org/10.1371/journal.pone.0088387 Owens and Malham (2015); https://doi.org/10.3390/jmse3010087 Saleh et al. (2016); https://doi.org/10.1089/nat.2016.0613 Huvenne and Smagghe (2010); https://doi.org/10.1016/j.jinsphys.2009.10.004 Xue et al. (2012); https://doi.org/10.1016/B978-0-12-387680-5.00003-3; isac_advanced_biotechnology_white_paper.pdf
Robotics	Remotely controlled robots to hunt invaders	Invasive lionfish hunted by autonomous underwater robots (e.g., Guardian LF1).	voanews.com/a/3824381.html
Smartphone technologies	Apps to rapidly identify and report invasives	"Squeal on pigs" – Provide landowners with the information they need to effectively and quickly report suspected sightings of feral pigs and provide states with tools to work with private landowners to eradicate known populations of feral pigs "Texas invaders" – Citizen science program collects species observations from volunteer "citizen scientists" trained to use a specially developed invasive species Early detection and reporting kit	apps.bugwood.org/apps easin.jrc.ec.europa.eu/easin/CitizenScience/BecomeACitizen
Sniffer dogs (molecular dogs)	Trained canines that can detect plants and animals, diseases, etc.	The "beagle brigade" consists of beagles trained by the US Department of Agriculture to detect invasive species at airports and borders. They serve as assistants to their human inspectors	www.cbp.gov/FY 2016 Agriculture Fact Sheet Update_OFO.pdf; www.nature.com/articles/s41598-019-52385-1; Goodwin et al. (2010); https://doi.org/10.1614/IPSM-D-09-00025.1

that hinders local action or makes IAS management more difficult at the local scale will be undesirable. An effective global strategy will facilitate nations to adopt parts of the strategy, or all of it, depending on their capacity and goals.

Building on the foundations of the GISP 2001 *Global Strategy on Invasive Alien Species* (Box 16.2), a five-point formulation is recommended to improve international capacity, prevention, and management of IAS through a global strategy:

1. **Better tools, indicators, and standards for long-term monitoring of biological invasions and management success at multiple scales**. Without a clear assessment of the magnitude and dynamics of biological invasions, it is impossible to establish a successful global strategy for their control. Thus, key indicators need to be established at multiple scales, from local to global scales. Countries should be required to make knowledge available about such indicators, and clear monitoring schemes ought to be implemented and followed consistently over time.
2. **Better techniques for the evaluation of impacts across different taxa and regions**. Quantitative estimations of the impacts of IAS on biodiversity, ecosystem services, and human well-being should be evaluated, and their results effectively communicated to all societies that are or may be affected. Likewise, national strategies should identify *agreed-upon management options* for controversial species (e.g., those producing both negative and positive impacts, e.g., see Pejchar and Mooney 2009; Kiviat 2013; Shackleton et al. 2014) and identify who should bear the costs of the negative impacts, as well as the costs and benefits of any control strategy. Equally important would be to weigh the gains and losses from such controversial taxa. Any assessment should also include the socioeconomic aspects (Bacher et al. 2018) and better techniques for communication, outreach, and citizen science that take into account different world views and values (Humair et al. 2014; Shackleton et al. 2019b) and enable collaboration with practitioners such as in the pet, aquarium, and plant trade industries (Hulme et al. 2018; Shackleton et al. 2019b).
3. **Better and additional legislation and normative tools (from global to local contexts)**. Preventing the introduction and spread of IAS requires strict regulations that may in some cases be considered adverse for some stakeholders. Thus, unless these regulations are supported by national legislations, it will be impossible to advance them based only on the recommendations or voluntary approaches or just by the broad global agreements. Efforts must be directed to translate global initiatives into instrumental local regulations (e.g., Perrings et al. 2010). For example, while there is a convention on ballast water slowly taking effect, and although managers and policymakers have recently come to recognize the importance of biofouling of commercial vessels and recreational boats in the dispersal of IAS, no international convention exists to address this issue (Galil et al. 2015). In addition, better and more effective regulations in the trade of pets and ornamental plants are certainly required (Patoka et al. 2018).
4. **Better global biosecurity and biosecurity awareness**. Hulme (2014) defines biosecurity as "the research, procedures and policies that cover the exclusion, eradication or effective management of the risks posed by the introduction of alien plant pests, animal pests and diseases, animal diseases capable of transmission to humans (zoonoses) – Covid-19, the current pandemic is a prime example (Nuñez et al. 2020) – the introduction and release of genetically modified organisms (GMOs) and their products, and the introduction and management of IAS and genotypes." This comprehensive definition incorporates patterns of trade and transport that facilitate species introductions (Meyerson and Mooney 2007). Nations such as Australia, New Zealand, and South Africa have invested heavily in biosecurity measures that include IAS as major biosecurity risks, while other countries like the United States have not heeded calls to include IAS as a significant biosecurity threat (Meyerson and Reaser 2002a, b; Meyerson

et al. 2019). Trade volume and international passenger travel have risen dramatically over the last several decades along with international trade agreements (Hulme 2014), all of which increase the risks of species introductions and overwhelm biosecurity efforts of many nations. Coupled with climate change and overall global human population growth, addressing biosecurity to include IAS adequately will require a global strategy. An approach known as the "biosecurity continuum" is a promising global strategy to raise awareness and reduce risks associated with the global movement of species. The biosecurity continuum efforts address the risks of IAS in three stages: (i) pre-border, to lower the risks posed by introductions from other countries; (ii) at the border, to stop IAS from entering a region; and (iii) post-border, to find and eradicate any IAS that were able to enter and establish (Caffrey et al. 2014; Hulme 2014). While implementing a biosecurity continuum on a global scale would present significant challenges, it could also provide substantial benefits to countries by demonstrating that their exports are IAS-free, thereby strengthening relationships among trading partners.

5. **Increase synergies with other strategies on biodiversity and environmental protection**. A significantly large percentage of the world's plant species, perhaps as many as 94,000–194,000, are at risk of extinction in the near future due to threats including habitat loss or degradation, overexploitation, biological invasions, industrialization, pollution, and climate change (Pitman and Jørgensen 2002; Brondizio et al. 2019). Efforts to conserve plant biodiversity are hindered by several factors, in particular by the lack of a comprehensive global inventory of plant species and insufficient data for assessment of the conservation status of each species (Miller et al. 2012). The Global Strategy for Plant Conservation (GSPC) was adopted in 2002 at the sixth meeting of the Conference of the Parties to the Convention on Biological Diversity at The Hague in the Netherlands to address these challenges, and it is a clear example of one strategy that could work synergistically with a global strategy on biological invasions, producing overarching mutual benefits. Databasing plant diversity and promoting Red List assessments are of course very important not only for plant conservation but also to evaluate the impacts of IAS and to identify priority IAS, pathways, or sites for action and management.

While knowledge and resources to address the challenges of IAS have increased exponentially over the last several decades, the available knowledge and technologies to manage biological invasions are not adequately reflected in global, regional, and national policies and strategies. Large gaps between science, management, and policy at various geopolitical scales still exist and necessitate an urgent need for more integrative approach across multiple scales and multiple stakeholder groups to bridge those gaps and reduce the impacts of biological invasions on biodiversity and human well-being. The modular global strategy model proposed in this chapter can be visualized as a set of Russian dolls – dolls of different sizes that nest inside one another. The different dolls represent different legal instruments and voluntary measures that together define the overall strategy for a particular region or the globe. Some countries may adopt many or all aspects of the strategy and will have many "dolls within dolls," while other nations will have fewer. Yet all the different "dolls" or strategies adopted by nations work together toward the same goal of reducing biological invasions and minimizing their impacts. Importantly, the "dolls" or strategies must be maintained to ensure that they continue to fit into other larger and smaller "dolls" or strategies and that others fit into them. In many cases, component laws and policies are modified without adequate attention being given to "parent" and "offspring" instruments, resulting in conflicting regulations and/or important issues "falling between the cracks" and being left out of policies.

This proposed approach for IAS is thus inclusive, adaptive, and flexible and moves toward global strategies for better preventing and managing biological invasions. Clearly, the world has a long way to go in terms of achieving such comprehensive global strategies. Nonetheless, as

existing networks that focus on biological invasions mature (Table 16.1) and new networks come online, and as partnerships between such networks with existing intergovernmental and international organizations with an IAS focus (Table 16.2) strengthen, achieving effective global strategies will become an attainable reality.

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