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Invasive species are a historical, long-term, and continually growing threat to the ecology, economy, and infrastructure of the United States. Widely recognized as one of the most serious threats to the health, sustainability, and productivity of native ecosystems, invasive species issues have commonly been viewed as problems specific to Federal, State, and private landowners. However, it is increasingly apparent that the impacts from these species are all encompassing, affecting ecosystem processes in addition to the economics of land management, public and private infrastructure, the energy sector, international trade, cultural practices, and many other sectors in the United States.

In the United States, the President issued Executive Order (EO) 13112 in 1999, providing a common definition of the term “invasive species” across the Federal agencies for the first time (see below). The definitions within the EO provided Federal agencies with consistent terminology that greatly facilitates discussion across taxa. Up until this time, invasive species issues were considered for individual taxa such as weeds, forest pests and diseases, aquatic animal species, and terrestrial animals. The common language provided by the EO also facilitated discussion at the international scale regardless of differing species of concern. Executive Order 13112 prompted basic research within the Federal scientific community concerning foreign exploration, ecological functioning,

pest detection, prevention of pest invasion, and control and management. In the time since the EO was signed, human and animal diseases have increasingly been included in the discussion of invasive species. Biosecurity has also become an issue as impacts on military readiness have become apparent.

Definitions within Executive Order 13112 Section 1:

(e) “Introduction” means the intentional or unintentional escape, release, dissemination, or placement of a species into an ecosystem as a result of human activity.

(f) “Invasive species” means an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health.

Executive Order 13112 also specifically defined invasive species as relating only to the introduction and movement “as a result of human activity.” This anthropogenic definition excluded natural background rates of species introductions by natural or nonhuman pathways such as natural disasters and animal movement. There was a great deal of discussion on this specificity in the definition from numerous viewpoints. However, many argued against an unrestricted definition because it would overlap with natural succession and other processes that are not driven by human activities, such as movement of species onto volcanic areas, new islands, or fire- or flood-ravaged areas.

The EO was intended to establish Federal Government definitions of key terms, with the hope that other public and private entities would adopt the definitions therein. However, many sectors use other terminology and definitions, and terminology continues to be debated in the literature. For example, terms such as “forest pests and diseases” are still used, including both native and non-native organisms. Other terms include “alien” or “exotic” and “nonindigenous” or “non-native.” Typically, these terms refer to non-native species that may or may not be invasive. Unfortunately, the need remains for an agreed-upon definition within the larger community concerned about invasive species. This assessment

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uses the EO 13112 definitions, and we avoid using other terms unless the cited source specifically uses them.

The issues surrounding invasive species are complex and diverse, interdisciplinary, and multi-jurisdictional and occur at local, landscape, national, and international scales. Issues also vary across temporal scales or invasion stage, such as species introduction, establishment, and spread, which impact options for control. Invasive plants, animals, diseases, and pathogens can affect ecosystems through changes in nutrient cycling, biodiversity, tree mortality, forest dynamics, fire regimes, and hydrology. Population dynamics and competitive interactions are affected as highly competitive invasive plants or insects can outcompete native species, creating monocultures and threatening or endangering native species. Current research examining the effect of climate change on invasive species' establishment and spread suggests that some invasive species (e.g., plants) may have more adaptive plasticity, with potential fitness advantages in the invaded range. Historical approaches to prevention, control, and management all need to be conducted with follow-up evaluation to determine the actual effectiveness of the measures taken or their effect upon the environment. As invasive species research has developed, more emphasis has been placed upon evaluating the effectiveness and economic viability of these measures and resources needed to reduce the introduction and spread of invasive species.

The purpose of this assessment is to present the state of science for invasive species studies, from impacts at the ecosystem and population levels to knowledge about international impacts and restricting vectors of introduction. Increased science that focuses on quantifying invasive species' biology, impacts, and interactions, along with managing invasive species and altered ecosystems, were identified as priorities in a USDA Forest Service Technical Report, *A Dynamic Invasive Species Research Vision: Opportunities and Priorities 2009–2029*. This assessment is largely restricted to exploration of topics associated with nonagricultural lands and does not extensively cover issues related to croplands, orchards, or vineyards, although some public forests and rangelands (e.g., national forests) are administered within the U.S. Department of Agriculture, and some may consider them agricultural lands due to the production of fiber and food. However, Chap. 9 provides a brief review of many invasive species impacts related to these other sectors. Key information and knowledge gaps are included for each chapter, and discussion is highlighted by region as well as in the appendices.

The first part of the assessment explores the ecological impacts of invasive species from aquatic species to insects and diseases. In Chap. 4, the authors discuss the potential influence of climate change on invasive species, and in Chap. 5, invasive species' response to natural and anthropogenic

disturbance is reviewed. Research applications for early intervention, prevention, and rapid response, and the challenges surrounding controlling established populations are presented in Chaps. 6 and 7. Chapter 8 reviews the relatively new topic of restoration and rehabilitation of lands after control or eradication. In some cases, the landscape needs rehabilitation before restoration can occur. Research has also shown that often the first plants coming into an area after a control action against an invasive plant is another invasive plant species. The national inventories presented in Chap. 10 provide information for conducting risk assessments to evaluate vulnerable ecosystems and enable models predicting spread, but not all species have reliable national data sets, and many local data sets remain isolated. Tools for quantifying spread and impacts of invasive species are discussed in Chap. 11, including newer technologies such as remote sensing and eDNA.

The authors of Chap. 12 present a valuable survey of social science research across a diversity of ecosystems and stakeholders that provides a foundation for understanding social and cultural dimensions of invasive species, including impacts on Native American tribes. The cultural impact of native species no longer available for Native American tribal rituals can be devastating. In addition, the perceptions and attitudes of affected human populations can have an enormous effect on the ability to direct resources for both State and Federal Government. Yet new social science approaches exist that are increasingly good at engaging these human populations through citizen science programs, bringing in the layperson, amateur, and paraprofessional into the discussion of what action an individual can take to influence the status of an invasive species on the ground.

Chapter 13 points out that international collaboration plays a key role in research on prevention of future invasions. In addition, understanding species in their native ranges and how they enter the invasion pathway is critical to the analysis of risk used to guide quarantine measures. Invasive species can also have a major impact on the economics of an area, as noted in Chap. 14. For example, the forest products and ranching industries have been greatly affected. Exploring the economics of invasive species also highlights the human dimensions of the topic, an important aspect regarding invasive species issues. The Federal legislation that provides standing for Federal actions on invasive species is highlighted in Chap. 15. Some of the most important Federal laws are aimed at preventing introduction and interstate spread of known or potential invaders, while other laws regulate modes of transport as well as the organisms themselves. Rarely has the impact of invasive species upon the sectoral parts of the U.S. economy, including military preparedness, human health, the energy and utility industry, and transportation infrastructure been examined. A general but not exhaustive review of sectoral values and impacts is

included in Chap. 9. These issues typically are not well known by the invasive species research and management community, and only recently have more rigorous and in-depth impact assessments become available.

This assessment synthesizes local to international research and information on a comprehensive array of topics pertinent to invasive species and identifies future needs and gaps for research. The information provided is intended to be useful for a range of stakeholders, including researchers, managers, and decision makers working on a variety of invasive species

issues. Much progress in research has been made on understanding the major aspects of invasive species, yet considerable challenges remain. Advances in these challenge areas are critical to improve prevention and management of invasive species and reduce impacts to humans and ecosystem services.

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