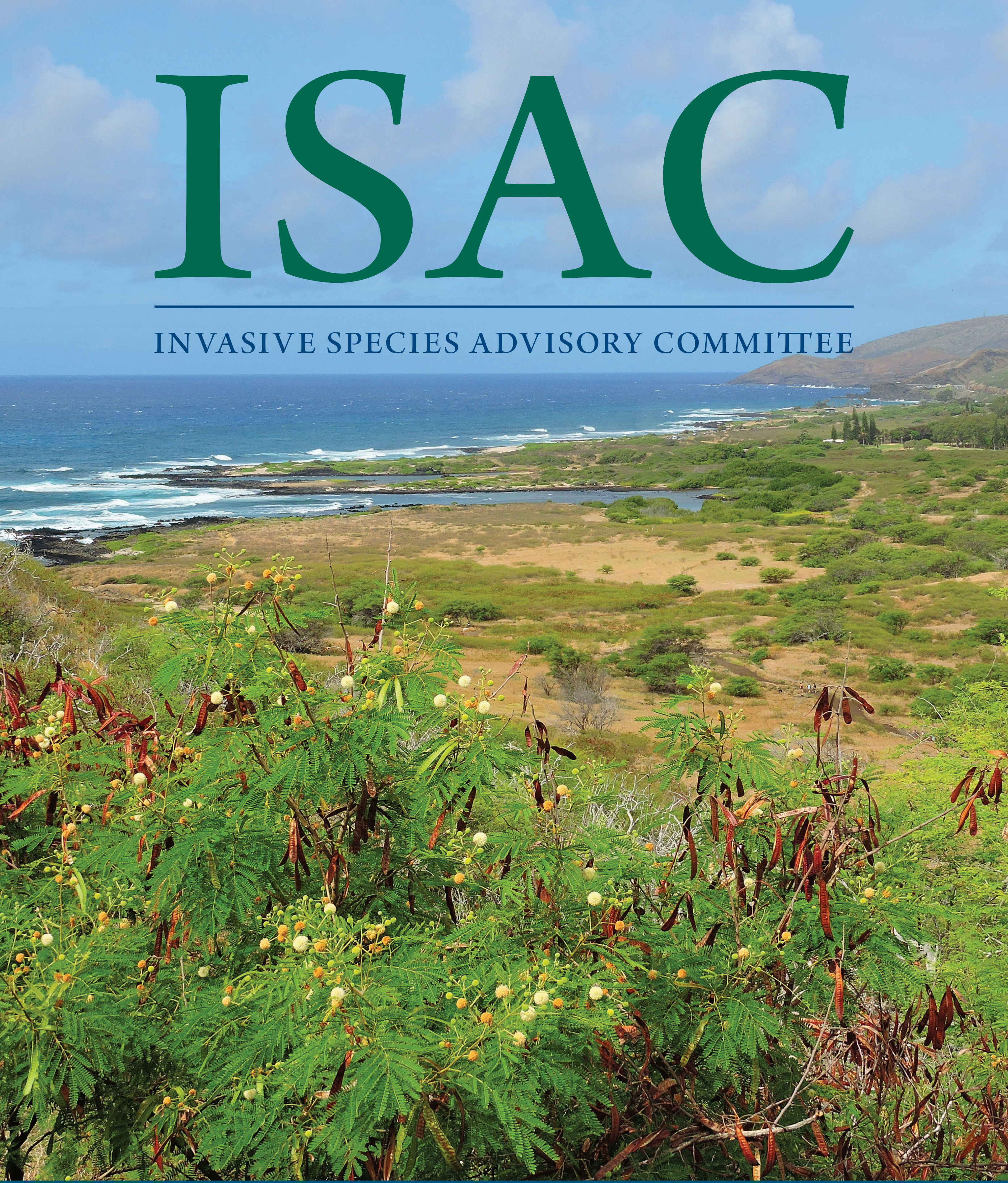
ISAC

INVASIVE SPECIES ADVISORY COMMITTEE



WHITE PAPERS & RECOMMENDATIONS

2006–2015

Contents

Summary of Recommendations

AUGUST 2009 | *Biofuels: Cultivating Energy, not Invasive Species*

To minimize the risk of biofuel crop escape into the surrounding environment, the U. S. government needs to employ and promote ecological studies and scientific models that characterize the invasion risk of each biofuel species or cultivar (as appropriate) within a target region and identify ecosystems most susceptible to invasion. Information generated from biofuel crop ecological studies, risk analyses, bioeconomic and climate match modeling, and other methods can guide the government's risk mitigation plans. Depending on their authorities, Federal agencies can take strategic steps at appropriate points within research and development, crop production, harvest and transportation, conversion/refinery practices, and/or regulatory action to minimize the risk of biofuel crops becoming invasive. ISAC recommends that the Federal government apply the following recommendations to its own biofuels programs, as well as use them as a basis for standards of operation when engaging with the private sector and other partners.

1. *Review/Strengthen Existing Authorities*

   Identify Federal authorities relevant to biofuels. Determine their likely influence on biofuel invasiveness (i.e., prevention or facilitation). Identify gaps and inconsistencies in authorities within and among Federal Departments or Agencies. As appropriate, develop policies and programs to minimize invasion risk.

2. *Reduce Escape Risks*

   In order to determine potential biofuel benefits and risks, the invasive potential of each candidate biofuel crop needs to be evaluated in the context of each region proposed for its production. Use/promote species (including unique genotypes) that are not currently invasive and are unlikely to become invasive in the target region. Choose species or cultivars with a low potential for escape, establishment and negative impact. Where appropriate, implement mitigation strategies and plans to minimize escape and other risks.

3. *Determine the Most Appropriate Areas for Cultivation*

   Ideally, biofuel crops should be propagated in containable systems (e.g., terrestrial or aquatic sites constructed specifically to cultivate biofuel crops) and be unable to survive outside of cultivation. Use research findings to identify the most appropriate sites (e.g., unlikely to impact sensitive habitat or create disturbances that will foster invasion) for cultivation of biofuel crops within landscapes. Support for biofuel research and demonstration projects will require site selection that minimizes the potential escape of plant species or cultivars to sensitive areas and the loss of wildlife habitat.

4. *Identify Plant Traits that Contribute to or Avoid Invasiveness*

   Incorporate desirable traits (e.g., sterility or reduced seed production, inability to regenerate by stem fragments) into biofuel varieties to minimize their potential for invasiveness. Use information from plant research, agronomic models, and risk analyses to guide breeding, genetic engineering, and variety selection programs.

5. *Prevent Dispersal*

   Develop and coordinate dispersal mitigation protocols prior to cultivation of biofuel plants in each region or ecosystem of consideration. Implement a comprehensive plan, appropriate to the specific crop, throughout the cultivation period. Examples of dispersal mitigation measures include the use of sterile cultivars, species not likely to genetically mix with other plants (different species or cultivars), harvesting prior to seed maturity, cleaning equipment, and minimizing propagule dispersal throughout the biofuel production cycle.

6. *Establish Eradication Protocols for Rotational Systems or Abandoned Populations*

   Proactively develop multiple year eradication protocols to plan for the rapid removal of biofuel crops if they disperse into surrounding areas or become abandoned or unwanted populations (e.g., those which persist beyond desired crop rotation period).

7. *Develop and Implement Early Detection and Rapid Response (EDRR) Plans and Rapid Response Funding*

   Develop EDRR plans that cover multiple years to eliminate or prevent establishment and spread of escaped invasive populations. A flexible funding source needs to be in place to support DRR efforts.

8. *Minimize Harvest Disturbance*

   Disturbed environments are especially prone to plant invasion. Minimize the soil disturbance resulting from biofuel harvest by rapidly replanting, using cover crops, or employing other methods that will prevent the potential for future invasion of non-native plants from the surrounding area into the harvested site.

9. *Engage Stakeholders*

   Identify and employ cooperative networks (e.g., working groups and councils), communication forums, and consultation processes through which the Federal agencies can work with state agencies, tribes, the private sector, and other stakeholders to reduce the risk of biological invasion via the biofuels pathway.

JUNE 2010 | *Invasive Species and Public Investment in the Green Economy*

We call on the member Departments and Agencies of the National Invasive Species Council (NISC) and potential partners to:

1. Establish a national survey of invasive species, to be administered at the state-level. Support this program by substantially increasing Federal and state jobs at all technical levels to survey, identify, map, catalog, and model patterns/trends of invasive plants and animals.[1] Include the existing state and regional invasive species committees/councils in the development and implementation process. Place priority on invasive species known or projected to have substantial impacts.

2. Supplement the Federal and state workforce by creating contract jobs in the private sector and offering grants to encourage business innovation and entrepreneurship (e.g., native plant and seed companies, ecosystem restoration, invasive species mapping and control services, and education/outreach programs).

3. In order to counter the dramatic decline in taxonomic capacity (i.e. the decrease in the number of people trained to identify specific species), provide grants to support research/education/training in taxonomy as well as job creation for taxonomists and parataxonomists (people who lack formal higher-level education, but who are trained to undertake species identification tasks).

4. Capitalize invasive species prevention and management needs (e.g., along roadways and on government lands) to create entry–mid level, high impact social development programs

1 In implementing this recommendation, capitalize on the mapping (etc.) that has already been accomplished.

for youth and persons at risk (e.g., minimum security prison population). Establish Federal initiatives and/or offer grants to states and tribes.

5. Substantially increase Federal and state agency staffing in the areas of import/border inspection for agriculture and wildlife (Reaser and Waugh 2007), specimen identification, pest risk analysis (including pre-import screening), and invasive species program management (esp. public education/outreach, regulatory enforcement, and early detection/rapid response).

6. Establish/strengthen internships in invasive species identification, control/eradication, mapping, and monitoring for high school and college students. Support comparable Federal, state, tribal, and non-profit initiatives.[2]

7. Develop stronger relationships between the Federal government and green industries potentially impacted by and/or managing invasive species. For example, work with the Invasive Species Advisory Committee (ISAC) and/or NISAW to organize an Invasive Species & Green Industries Summit.

8. Mandate that, prior to receiving Federal support: 1) renewable energy projects (esp. solar, wind, and biofuel) have adequate invasive species mitigation plans in place and 2) biofuel developers/producers demonstrate that non-native species are of low invasion risk (to the propagation site, area of potential dispersal, and along transport pathways) based on a competent invasive species risk analysis.[3]

DECEMBER 2010 | *Invasive Species and Climate Change*

We call on the member Departments and Agencies of the National Invasive Species Council and potential partners to:

1. Use the Global Change Research Act of 1990 (GCRA)48 (PL 101-606) to aggregate information about the implications of a changing climate for invasive species spread so scientific data may be synthesized through existing authorities to inform policy-makers.

2. Streamline and focus agency programs to address invasive species climate interactions effectively and efficiently by establishing: 1) strategic plans that anticipate climate impacts on invasives, 2) forward-looking environmental compliance documents (e.g., NEPA, nationwide Environmental Impact Statements on invasives prevention, management, and restoration), and 3) focus awareness programs to anticipate and manage potential climate driven ecosystem changes.

3. Assess new climate driven invasion pathways and strengthen prevention programs to address invasives in ballast water, bio-fouling, interstate and international movement of materials and equipment (e.g., energy development, wildfire response, national defense), and screening of plant and animal imports taking account of climate impacts.

4. Support monitoring and adaptive management programs for invasive species at the landscape scale so that natural resource managers can identify new threats and respond quickly and appropriately to invasive species in changing climatic conditions.

5. Foster collaboration of existing networks to address the broad geographic nature and altered management of invasive species issues in a time of climate change. This will allow the national response to be coordinated, efficient, and capitalize on current capacities using a synergistic approach.

6. Increase research and development targeted at climate change and invasive species by supporting and expanding the USDA-ARS and U.S. Forest Service Climate Change Programs, as

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2 For example, the Youth Conservation Corps and the Student Conservation Association.

3 For more information, see ISAC briefing paper, "Biofuels: Cultivating Energy, not Invasive Species;" www.invasivespecies.gov.

well as competitive research programs such as USDA's Agricultural and Food Research Initiative, the Environmental Protection Agency's Project Grants, National Science Foundation's Conservation and Biology program, and NOAA's Sea Grant program. Better understanding of the interaction of climate change and invasive species will result in more relevant prioritization and management on the ground. This includes recognizing the economic basis for invasive species management decisions and supporting work that integrates economic, ecological, and biological data providing policy and management support.

7. Use climate matching and ecological niche models to prioritize management of species that are most likely to cause the greatest harm in the future as a result of climate change.

This will require the Federal response to be coordinated, empowered, and appropriately funded.

JUNE 2011 | *Marine Bioinvasions and Climate Change*

Changes in the Earth's climate will likely continue, or even accelerate, over the next century. The economic, energy, social, and environmental impacts of invasions mediated by climate change may be profound. Our understanding of climate-driven species movements is only the tip of the iceberg: a great many more species are in motion. Predictions of how species and their habitats will respond to climate change will assist in making conservation decisions and managing our natural resources. Invasive species management will need to develop tools that include both invasion biology and climate change impacts. The following are recommendations to assist the development of such tools:

1. *Fund Research Programs*

   Dedicated research programs across a diversity of regions (e.g. high, mid and low latitude sites) must be developed and adequately funded to detect species movements and likely interspecies interactions, in order to predict, and possibly prevent, the impact of invasion resulting from global climate change. These goals will best be accomplished via focused, mechanistic studies of invasive species to inform and predict how global climate change factors may impact native species, invasive species and interact with local stressors to affect invasion success.

2. *Increased Coordination*

   Build partnerships among federal agencies and academic institutions to enhance capacity for detecting, responding to, and managing invasive species.

3. *Develop Rapid Response Plans*

   Risk assessments are needed to prioritize species that deserve rapid responses. Strategies need to be developed for rapid response to these species. Further, an emergency fund for such efforts should also be established.

4. *Vector Management*

   These scenarios of the "ghost of Christmas future" support the need to strikingly enhance vector management policies to prevent future invasions.

5. *Expand Educational and Outreach Programs*

   It is imperative for the public to understand the implications of their actions, with or without the climate change message. Increased efforts should be initiated to translate the combined risks from climate change and biological invasion to the public through real-world examples.

6. *National Strategy for Monitoring*

Global climate change will result in the loss of species; yet without adequate monitoring the extent of this loss may not be known. For example, some species are endemic to Alaska; however, as a result of the large size and remoteness of the state, many species still are unknown. Extensive monitoring across environments is needed to document the distribution of native species, identify range shifts, and detect invasions.

MAY 2012 | *Validation of PCR-Based Assays and Laboratory Accreditation for Environmental Detection of Aquatic Invasive Species*

To encourage the development of a validation/accreditation system for AIS eDNA detection methodologies and laboratories, ISAC recommends that the NISC member Departments and Agencies and their partners consider adoption of the following recommendations.

1. Encourage and develop funding for the National Academy of Sciences to undertake a review of the reliability and effectiveness of PCR and other DNA-based applications for detecting AIS, focusing on establishment of appropriate validation processes and a framework and standards for this new and potentially invaluable tool in the early detection, eradication, prevention and control of AIS.

2. Establish and fund an ongoing independent performance testing program for laboratories utilizing DNA-based AIS detection methodologies such as that recently undertaken for evaluating laboratory performance in PCR detection of dreissenid mussel larvae (Frischer et al. 2011). Testing results should be made public so that managers may make informed decisions about the accuracy and reliability of a laboratory's performance when including an eDNA component in an AIS monitoring and early detection system.

3. Utilize lessons learned in establishing a laboratory performance testing system to fully develop a validation/accreditation program(s) for other invasive species eDNA methodologies and laboratories.

MAY 2012 | *Invasive Species and E-Commerce*

We conclude that relevant federal agencies need to adjust existing regulations and enforcement practices to better mitigate the risks of trade and transport of invasive species through e-commerce. We offer the following recommendations to enhance our collective ability to engage in e-commerce without promoting the introduction or spread of invasive and potentially invasive species.

1. U.S. Fish and Wildlife Service (DOI) and Animal and Plant Health Inspection Service (USDA): Expedite listing processes for the national importation of injurious wildlife and other animals and noxious plants under the Lacey Act, the Plant Protection Act and the Animal Health Protection Act to better assess and address emerging invasive species threats, including those associated with e-commerce.

2. U.S. Fish and Wildlife Service (DOI): Incorporate all species-specific data submitted with Form 3- 177 declarations for wildlife imports into the Law Enforcement Management Information System (LEMIS) or another accessible database.

3. Department of Homeland Security: Expand cooperation with the U.S. Postal Service to monitor and increase the capability to interdict international mail containing potentially invasive species and encourage the U.S. Postal Service to expedite requirements for advance electronic manifests associated with packages sent through international mail similar to current practice for international express mail and consignments.

4. Animal and Plant Health Inspection Service (USDA): Expand the scope of webcrawlers and related enforcement and monitoring activities used by the Smuggling Interdiction and Trade

Compliance unit to include a broader array of invasive plants and plant pests, and enhance cooperation with

5. U.S. Fish and Wildlife Service (DOI) to address injurious wildlife.

6. Agricultural Research Service (USDA): Support development of and capacity for an Internet clearinghouse of federal and state-listed invasive species such as injurious wildlife, other animals and noxious weeds and of relevant regulations. Such a resource could be located at the National Agricultural Library's Invasive Species Information Center or another appropriate website and should include relevant agency contact information and a general reporting form that allows the public to report suspected violations.

7. U.S. Fish and Wildlife Service (DOI), Animal and Plant Health Inspection Service (USDA), National Oceanic and Atmospheric Administration (Department of Commerce [DOC]) and other relevant agencies: Provide a reference catalog or database of taxonomic resources that commercial interests can use to verify the taxonomic identity of organisms in trade.

8. Department of State and Office of the U.S. Trade Representative: Given that a significant portion of e-commerce entities is based outside the U.S., explore further cooperative and legal measures with foreign trading partners and relevant international institutions and other bodies to address the illegal import of invasive species into the U.S.

9. U.S. Fish and Wildlife Service (DOI), Animal and Plant Health Inspection Service (USDA), National Oceanic and Atmospheric Administration (DOC): Promote outreach to individuals and businesses involved in the sale and exchange of species over the Internet to reduce intentional and unintentional sales or purchases of species listed as invasive in the U.S. or particular states.

MAY 2014 | *Harvest Incentives: A Tool for Managing Aquatic Invasive Species*

Incentivized harvest is just one type of strategy used to manage and control invasive species. As dedicated funding for invasive species management is limited, resource managers should conduct a basic analysis of various options based on the life history of the target species and relevant socioeconomic factors to identify the most effective solution. The anticipated costs and risks of eradication should be weighed against long-term control and management that mitigates damage to an acceptable level. ISAC recommends the following be considered before implementing any harvest incentive program:

1. *Develop a management plan prior to undertaking a harvest incentive program. The plan should incorporate each of the following:*

   a. Program goals and measures of success: The goal of the program and the method used to measure progress toward completion of the goal should be clearly identified.
   b. Cost analysis: Once the decision has been made to reduce numbers of a specific invasive species, then costs (both monetary and welfare) of various potential control methods should be compared to identify the most cost-effective method.
   c. Target species' biology: Managers should gather the best available information about the species.
   d. Address humane treatment: Processes for humane treatment of target species, including euthanasia, should be established.
   e. Human and wildlife health risks: Before managers encourage harvest, they should ensure that the target species and the associated harvest activities do not pose a significant risk to human or wildlife health through any aspect of the harvest program.
   f. Potential ecological outcomes: Species interactions and the effect of removing or reducing the target species from the ecosystem should be evaluated prior to program start.
   g. Risk of creating perverse incentives: Before initializing a program, identify the possible perverse incentives that may exist and include a plan to address them.

2. *Incorporate the following into the implementation of any harvest incentive program after the development of a management plan:*

a. Monitor for unintended consequences: Incentive programs and commercialized harvest of invasive species may create perverse incentives that do little to encourage long-term control or eradication. The program should be adequately supervised to prevent such occurrences.
b. Monitor for ecological disturbances: Project activities should be evaluated to reduce any potential disturbances to native populations or habitats.
c. Incorporate adaptive management: Harvest may be successful early on when there are large, easily accessible populations, but other control measures may be needed as species density declines or if methods are unsuccessful.
d. Encourage active enforcement to help mitigate perverse incentives by creating a disincentive to release the target species back into the control area or previously non-invaded areas.

3. *Incorporate Outreach*

a. All outreach should be clear about the goals of the program to encourage public and stakeholder support throughout the development, implementation and completion the program.
b. All outreach should help ensure that public does not grow to "desire" the targeted species. Success is more likely if the public understands the long-term harm the species can cause.
c. When outreach is the primary objective of a harvest program be sure to carefully plan for maximum media exposure.

MAY 2015 | *Background Paper on Systematics*

ISAC recommends that:

1. The USDA Agricultural Research Service (ARS) and the Smithsonian Institution conduct a survey and gap analysis of their Federal systematics collections, associated resources, and capabilities.

2. Survey results should be translated into an ARS 10 Year Systematics Action Plan and a Smithsonian Institution 10 Year Systematics Action Plan.

3. The Plans should be used by agency leaders to improve the systematics capabilities and resources of the agencies in all taxa to strengthen their ability to predict, prevent and manage invasive species.

4. The coordination of federal systematics efforts referenced in the Federal Interagency Committee for Invasive Terrestrial Animals and Pathogens (ITAP) *Situation Report* should be implemented.[4]

5. The ITAP's Systematics Subcommittee should assist the agencies in the Surveys recommended by the Situation Report.

OCTOBER 2015 | *Enhancing the Effectiveness of Biological Control Programs of Invasive Species by Utilizing an Integrated Pest Management Approach*

Recognizing that biological control of widespread established invasive species can be the most cost-effective sustainable control mechanism, particularly as part of an integrated pest management (IPM) program, ISAC recommends:

1. Federal-land management agencies that oversee and conduct control operations utilizing biological control agents should do so in the context of an adaptive IPM strategy by partnering

4 Federal Interagency Committee on Invasive Terrestrial Animals and Pathogens (ITAP) Systematics Subcommittee. 2008. Protecting America's Economy, Environment, Health, and Security against Invasive Species Requires a Strong Federal Program in Systematic Biology.

with federal, state, tribal, and local scientists and agencies of relevant pest-management disciplines to improve the effectiveness of biological control agents.

2. Federal land-management agencies should place increased emphasis on post-release monitoring to provide feedback and input to the decision-making process and enhance the success and economic performance of biological control programs. To accomplish this, project funding must be assured for the full duration of the project, as well as the broader framework of the IPM approach.

3. Federal land-management agencies should include long-term stewardship and sustainability of desired ecosystem functions as the ultimate goal of all biological control programs. To this end, IPM programs may include ecological rehabilitation that will provide resilience to the ecosystem and help prevent re-invasion or replacement of one invasive species with another. This will require coordination among many local, state, tribal, and federal agencies, including those responsible for developing the biological control programs and those in charge of resource management.

4. Responsible federal agencies should give increased attention during selection of biological control agents for release to: 1) characterizing natural enemy candidates using morphological taxonomy or genetic markers at the onset of a program, 2) utilizing climatic matching models to accurately determine the most likely areas of successful establishment of candidate agents, 3) understanding biological control agent host-finding behavior and attack rates/efficacy, and 4) recognizing the most relevant habitat characteristics/associations of biological control agents in their place of origin to better predict rates of colonization, spread, and impact in the invaded range.

5. When biological control is used, federal land management agencies should consider utilizing the information made available from the federal regulatory agencies to more effectively implement biological control programs.

ISAC
INVASIVE SPECIES ADVISORY COMMITEE

U.S. Department of the Interior
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Invasive Species Definition Clarification and Guidance

Approved by ISAC on April 27, 2006
Submitted by the Definitions Subcommittee of the Invasive Species Advisory Committee (ISAC)

PREAMBLE

Executive Order 13112 defines an invasive species as "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health." In the Executive Summary of the National Invasive Species Management Plan the term invasive species is further clarified and defined as "a species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health." To provide guidance for the development and implementation of the Management Plan, the National Invasive Species Council (NISC) and the Invasive Species Advisory Committee (ISAC) adopted a set of principles outlined in Appendix 6 of the Management Plan. Guiding Principle #1 provides additional context for defining the term invasive species and states "many alien species are non-invasive and support human livelihoods or a preferred quality of life." However, some alien species (the term non-native will be used in this white paper because it is more descriptive than alien), for example West Nile virus, are considered invasive and undesirable by virtually everyone. Other non-native species are not as easily characterized. For example, some non-native species are considered harmful, and therefore, invasive by some sectors of our society while others consider them beneficial. This discontinuity is reflective of the different value systems operating in our free society, and contributes to the complexity of defining the term invasive species.

NISC is engaged in evaluating and updating the 2001 Management Plan and is developing comments for a revised action plan as required by the E.O. 13112. While there have been numerous attempts to clarify the term invasive species, there continues to be uncertainty concerning the use and perceived meaning of the term, and consequently over the prospective scope of actions proposed in the Management Plan. Options related to private property use, pet ownership, agriculture, horticulture, and aquaculture enterprises may be affected depending upon the definition, use, and policy implications of the term.

In particular, the desire to consider a non-native species as "invasive" may trigger a risk/benefit assessment process to determine whether regulatory action is warranted. All these uncertainties have stood and could continue to stand in the way of progress in actions and policy development to prevent new invasions and manage existing invasive species. While it is not the purpose of this white paper to define a risk/benefit assessment process, development of such a process must be open and efficient to minimize the uncertainties.

This white paper is intended to provide a non-regulatory policy interpretation of the term invasive species by identifying what is meant, and just as important, what is not meant

Weeds as Examples

Weeds provide good examples to clarify what is meant by an invasive species because most people have a concept of what constitutes a "weed."

Invasion can be thought of as a process that in our example, a plant must go through to become a successful, yet harmful invader. Several barriers must be overcome for a plant to be considered an invasive weed. Invasive weeds are invasive species.

LARGE-SCALE GEOGRAPHICAL BARRIERS

First, a geographical barrier first must be overcome, which often occurs as a mountain range, ocean, or similar physical barrier to movement of seeds and other reproductive plant parts. Plants that overcome geographical barriers are known as alien plants or alien species. Alien plants are non-native plants and alien species are non-native species. Therefore, non-native plants are those that occur outside their natural range boundaries, and this most often is mediated by humans either deliberately or unintentionally.

SURVIVAL BARRIERS

The second set of obstacles that a non-native plant must overcome is barriers to germination and survival in its new location. These typically are environmental barriers such as adequate moisture availability to allow successful germination and survival of seedlings that will continue to grow to maturity. Other physical barriers might be soil pH, nutrient availability, or competition for resources from neighboring plants.

Weeds as Examples, continued

ESTABLISHMENT BARRIERS

The third obstacle that a non-native plant must overcome to be considered an invasive weed, is to form a population that is self-sustaining and does not need re-introduction to maintain a population base such that it continues to survive and thrive in its new environment. Once this occurs, this population of non-native plants is considered to be established. Environmental barriers to survival and establishment are similar.

DISPERSAL AND SPREAD BARRIERS

Established non-native plants must overcome barriers to dispersal and spread from their site of establishment to be considered invasive plants. Additionally, the rate of spread must be relatively fast. However, this movement or spread alone does not necessarily make this non-native plant an invasive weed or invasive species.

HARM AND IMPACT

Finally, a plant is deemed to be invasive if it causes negative environmental, economic, or human health effects, which outweigh any beneficial effects. For example, yellow starthistle is a source of nectar for bee producers. But the displacement of native and other desirable plant species caused by yellow starthistle leads to dramatically decreased forage for wildlife and livestock, which severely disrupts the profitability of associated businesses. These negative effects greatly overshadow the positive effects and thus, define harm caused by yellow starthistle and explain why it is considered an invasive species.

by the term. ISAC recognizes that biological and ecological definitions will not precisely apply to regulatory definitions. We believe, however, that our clarification will apply to *all taxa of invasive species in all habitats* and furthermore, our explanation will be functional and acceptable to most stakeholders. ISAC simply wants to clarify what is meant and what is not meant by the term invasive species in the technical sense and to provide insight into those areas where societal judgments will be necessary to implement effective public policy.

The utility of our clarification should be in education, conflict resolution, and efficiency in the planning, prevention, control/eradication, and management of invasive species.

ISAC recommends that NISC adopt the clarifications presented in this white paper to foster progress for invasive species management in the United States.

INTRODUCTION

An invasive species is a non-native species whose introduction does or is likely to cause economic or environmental harm or harm to human, animal, or plant health. The National Invasive Species Management Plan indicates that NISC will focus on non-native organisms known to cause or likely to cause negative impacts and that do not provide an equivalent or greater benefit to society. In the technical sense, the term 'invasion' simply denotes the uncontrolled or unintended spread of an organism outside its native range with no specific reference about the environmental or economic consequences of such spread or their relationships to possible societal benefits. However, the policy context and subsequent management decisions necessitate narrowing of what is meant and what is not meant by the term invasive species. Essentially, we are clarifying what is meant and not meant by "causing harm" by comparing negative effects caused by a non-native organism to its potential societal benefits.

PERCEPTION TO CAUSE HARM

Complications concerning the concept of invasive species arise from differing human values and perspectives. Differing perceptions of the relative harm caused or benefit gained by a particular organism are influenced by different values and management goals. If invasive species did not cause harm, we would not be nearly as concerned. Perceptions of relative benefit and harm also may change as new knowledge is acquired, or as human values or management goals change.

For a non-native organism to be considered an invasive species in the policy context, the negative effects that the organism causes or is likely to cause are deemed to outweigh any beneficial effects. Many non-native introductions provide benefits to society and even among species that technically meet the definition of invasive, societal benefits may greatly exceed any negative effects (for example crops and livestock raised for food). However, in some cases any positive effects are clearly overshadowed by negative effects, and this is the concept of causing harm. For example, water hyacinth has been popular in outdoor aquatic gardens but its escape to natural areas where its populations have expanded to completely cover lakes and rivers has devastated water bodies and the life they support, especially in the southeastern U.S. And, there are some organisms, such as West Nile virus, that provide almost no benefits to society at all. Such organisms constitute a small fraction of non-native species, but as a consequence of their ability to spread and establish populations outside their native ranges, they can be disastrous for the natural environment, the economies it supports, and/or public health. Because invasive species management is difficult and often very expensive, these worst offenders are the most obvious and best targets for policy attention and management.

The negative impact to a native species caused by an invasive species might trigger additional negative interactions for other associated native species (i.e., there could be direct and indirect effects). For example, an invasive weed that is undesirable as a food source may outcompete and displace native grasses and broadleaf plants. These displaced native grasses and broadleaf plants may have been primary forage for animals, which subsequently would be displaced to a new location or have their populations reduced because the weed invasion decreased the availability of food in their native plant and animal community. However, negative effects are not always characterized by a cascade of impacts realized throughout the environment. For example, simple displacement of an endangered species by a non-native species might alone provide sufficient justification to consider the non-native organism an invasive species.

WHAT WE DO NOT MEAN, WHAT WE DO MEAN, AND THE "GRAY" AREA

Native and Non-native Species

Invasive species are species not native to the ecosystem being considered. Canada geese are native to North America and most of their populations migrate annually. However, in some locations in the U.S. (e.g. suburban Maryland; the Front Range of Colorado) introduced, non-migratory populations of Canada geese are causing problems—such as fouling lawns, sidewalks, grass parks, and similar areas. While non-migratory populations can cause problems, they are not considered an invasive species because they are native. Additionally, Canada geese are of significant financial value to many local economies through waterfowl hunting and simple enjoyment. Mute swans, however, are invasive. Mute swans are native to Europe and Asia but were introduced into North America where their populations have increased dramatically. They compete directly with native waterfowl for habitat, displacing them, and that is why they are considered an invasive species. Whitetail deer populations have increased dramatically in the northeastern U.S. and are problems in farms, yards, and natural areas because they consume plants valued by humans; but are not invasive because they are native. Nutria, on the other hand, are another classic example of an invasive species. Nutria are native to South America but were introduced into North America, where their populations have soared. Nutria compete directly with native muskrats, beavers, and other similar native species for habitat; often causing the displacement of these native species.

Feral Populations

It is also essential to recognize that invasive species are not those under human control or domestication; that is, invasive species are not those that humans depend upon for economic security, maintaining a desirable quality of life, or survival. However, the essential test is that populations of these species must be under control. Escaped or feral populations of formerly domesticated plants and animals would be considered invasive species if all the concepts and conditions are met as outlined in "Weeds as Examples." Cereal rye being produced on a farm in Kansas is considered very desirable, but feral rye on the breaks of the Poudre River in Colorado would be considered an invasive species because it is displacing native plants and the native animal communities they support. Domesticated goats on a farm in Texas are considered highly desirable, but feral goats in Haleakala National Park on Maui are considered an invasive species. Feral goats have severely overgrazed areas and eliminated native Hawaiian plants, which were never adapted to grazing. Areas denuded by feral goats have led to increased soil erosion.

A Biogeographical Context

An invasive species may be invasive in one part of the country, but not in another. A biogeographical context must be included when assessing whether a non-native species should be considered an invasive species. Lake trout are highly desirable in the Great Lakes where they are native, but are considered an invasive species in Yellowstone Lake. They compete with native cutthroat trout for habitat, which decreases their populations. Atlantic saltmarsh cordgrass is an essential component of east coast salt marshes, but is highly invasive on the west coast where it covers mudflats and displaces native estuarine plants and the community of animals they support, including huge flocks of migrating waterfowl. Kentucky bluegrass would be considered an invasive species in Rocky Mountain National Park in Colorado, but considered non-invasive a mere 60 miles away at a golf course in Denver. English ivy is considered a good ground cover species in the Great Plains and Midwest, but is a highly invasive weed in the forests of the Pacific Northwest and Eastern U.S. where it outcompetes native plants and displaces the associated animal communities.

The "Gray" Area

There are obvious examples of invasive species such as snakehead fish, yellow starthistle, or *Phytophthora ramorum* (the organism that causes sudden oak death); and there are obvious examples of species that are not invasive, namely native plants and animals. There are, however, non-native organisms for which it will be difficult to make a determination and these should be subject to assessment. Whether these non-native organisms will be considered invasive species will depend upon human values. For example, European honeybees are cultured to produce honey and pollination services, and even though they form wild populations in many parts of the country and occasionally create problems by building hives in the walls of homes or can be a human health problem for individuals that are highly allergic to their sting, most would not consider them an invasive species because they produce a desired food product.

Another gray area example would be native termites v. Formosan termites. No one wants termites in their homes but only Formosan termites would be considered an invasive species because they are non-native. Smooth brome also serves as another gray area example. It was imported from Russia in the 1890s for forage and was widely planted. It clearly has escaped cultivation and can be found in many natural areas particularly in the western U.S. but in most situations, smooth brome would not be considered an invasive species because of its forage value for wildlife and livestock.

Chinese or Oriental clematis serves as another gray area example. Chinese clematis (virgin's bower, orange peel) is a popular ornamental that has been planted worldwide. However, it has escaped cultivation in several western states where its populations can spread, particularly in shrubland, on riverbanks, sand depressions, along roadsides, in gullies, and along riparian forests in hot dry valleys, deserts, and semi-desert areas. Escaped populations of Chinese clematis occur in Idaho, Nevada, Utah, New Mexico, and Colorado but so far, it is considered an invasive species only in Colorado where it has spread dramatically from its site of introduction and displaced native plant species.

Environmental Harm

We use environmental harm to mean biologically significant decreases in native species populations, alterations to plant and animal communities or to ecological processes that native species and other desirable plants and animals and humans depend on for survival. Environmental harm may be a result of direct effects of invasive species, leading to biologically significant decreases in native species populations.

Examples of direct effects on native species include preying and feeding on them, causing or vectoring diseases, preventing them from reproducing or killing their young, out-competing them for food, nutrients, light, nest sites or other vital resources, or hybridizing with them so frequently that within a few generations, few if any truly native individuals remain. Environmental harm includes decreases in populations of Federally Listed Threatened and Endangered Species, other rare or uncommon species and even in populations of otherwise common native species. For example, over three billion individual American chestnut trees were found in U.S. forests before the invasive chestnut blight arrived and virtually eliminated them. Environmental harm also can be the result of an indirect effect of invasive species, such as the decreases in native waterfowl populations that may result when an invasive wetland plant decreases the abundance of native plants and thus, decreases seeds and other food that they provide and that the waterfowl depend upon.

Environmental harm also includes significant changes in ecological processes, sometimes across entire regions, which result in conditions that native species and even entire plant and animal communities cannot tolerate. For example, some non-native plants can change the frequency and intensity of wildfires, or alter the hydrology of rivers, streams, lakes and wetlands and that is why they are considered invasive species. Others can significantly alter erosion rates. For example, trapping far more wind-blown sand than native dune species, or holding far less soil than native grassland species following rainstorms. Some invasive plants and micro-organisms can alter soil chemistry across large areas, significantly altering soil pH or soil nutrient availability. Environmental harm also includes significant changes in the composition and even the structure of native plant and animal communities. For example, the invasive tree *Melaleuca quinquinervia*, can spread into and take over marshes in Florida's Everglades, changing them from open grassy marshes to closed canopy swamp-forests.

Environmental harm may also cause or be associated with economic losses and damage to human, plant and animal health. For example invasions by fire promoting grasses that alter entire plant and animal communities eliminating or sharply reducing populations of many native plant and animal species, can also lead to large increases in fire-fighting costs and sharp decreases in forage for livestock. West Nile virus is a well-known human health problem caused by a non-native virus which is commonly carried by mosquitoes. West Nile Virus also kills many native bird species, causing drastic reduction in populations for some species including crows and jays.

ADDITIONAL EXAMPLES OF IMPACTS CAUSED BY INVASIVE SPECIES

Specific examples of the harm caused by invasive species are useful to further clarify the definition. The following list of examples is not meant to be comprehensive, but offers further explanation:

Impacts to Human Health

Respiratory Infections

The outbreak of West Nile virus in the U.S. began in the Northeast in 1999 and has since spread throughout the country. Infections in humans may result in a flu-like illness and in some cases death. This outbreak has caused illness in thousands of citizens, increased medical costs for affected persons, and decreased productivity due to absence from work. West Nile virus also has affected horses and has caused widespread mortality in native birds (U.S. Centers for Disease Control 2006).

Poisonous Plants

Exposure to the sap of Tree-of-heaven/Chinese sumac tree has caused inflammation of the heart muscle (myocarditis) in workers charged to clear infested areas. Afflicted personnel experienced fever/chills, chest pain that radiated down both arms, and shortness of breath. Exposure occurred when sap from tree-of-heaven contacted broken skin. Such exposure has caused hospitalization, medical expense, and lost productivity due to absence from work (Bisognano et al. 2005).

Impacts to Natural Resources

Declines in Wildlife Habitat and Timber Availability

Chestnut blight is a disease of American chestnut caused by a non-native fungal pathogen that was introduced into eastern North America around 1910. The disease eliminated the American chestnut from eastern deciduous forests thereby decreasing timber harvests and wildlife that depended upon the American chestnut for habitat (USDA-APHIS/FS 2000).

European gypsy moth defoliates trees on millions of acres of northeastern and mid-western forests. It currently is found in nineteen states causing an estimated $3.9 billion in tree losses and also decreased wildlife habitat (USDA-APHIS/FS 2000).

Decreased Soil Stabilization and Interrupted Forest Succession

White pine blister rust is a disease of white pine species caused by the non-native fungal pathogen, *Cronartium ribicola*. It was introduced into eastern North America around 1900 and western North America in 1920. It spread rapidly, killing off native white, whitebark, and limber pines, whose seeds are an important food source for birds, rodents, and bears. Elimination of these trees caused by this pathogen alters forest ecosystems, eliminates wildlife forage, and decreases the soil stabilization effects of these trees, snowmelt regulation, and forest succession (Krakowski et al. 2003).

Changes in Wildfire Frequency and Intensity

Cheatgrass decreases the interval between the occurrences of wildfires in the Great Basin region from once every 70 to 100 years to every 3 to 5 years because it forms dense stands of fine fuel annually. The decrease in interval between wildlfires causes increased risk to human life and property and also places at risk established communities of plants and animals that we consider desirable (Knapp 1996; Pimentel et al. 2000; USFWS 2003; Whisenant 1990).

Excessive Use of Resources

Tamarisk in the desert southwest use more than twice as much water annually as all the cities in southern California, which places this invasive weed in direct competition with humans for the most limiting resource in the southwestern U.S. (Friederici 1995; Johnson 1986).

Suppressors

Russian knapweed exudes toxins from its tissues that inhibit the growth of surrounding plants or eliminates them. Desirable plant communities are placed at risk from Russian knapweed invasion, which may result in decreased numbers of wildlife species or livestock that the invaded land otherwise could support. Russian knapweed also is very toxic to horses (Stevens 1986; Young et al. 1970a and 1970b).

Decreased Carrying Capacity for Wildlife and Livestock

Expansion of leafy spurge, yellow starthistle, or other unpalatable invasive weeds displace desirable forage plants and may allow fewer grazing animals to survive in infested areas (DiTomaso 2001; Lym and Messersmith 1985; Lym and Kirby 1987).

Impacts to Recreational Opportunities and Other Human Values

Decreased Property Values

Asian longhorned beetles first appeared in New York in 1996 and in Chicago in 1998. Larvae burrow into trees causing girdling of stems and branches, dieback of the crown, and can kill an entire tree. It infests many different tree species in the U.S. and is a threat to urban and rural forests (Cavey et al. 1998).

Emerald ash borers were first detected in the U.S. in 2002. They currently are found in Michigan, Ohio, and Indiana. Emerald ash borer larvae tunnel under bark of ash trees and could eliminate ash as a street, shade, and forest tree throughout the U.S. Estimated replacement cost in six Michigan counties is $11 billion and an additional $2 million in lost nursery sales (Chornesky et al. 2005).

Dutch elm disease was first introduced into the U.S. in 1927 and occurs in most states. Dutch elm disease has killed more than 60% of elms in urban settings and decreased the value of urban and suburban properties (Brasier and Buck 2001).

Spotted knapweed and leafy spurge expansion in the western U.S. have displaced desirable forage plants thereby decreasing the value and sales price of grazingland in the western U.S. (Maddox 1979; Weiser 1998).

Eurasian watermilfoil was introduced into the U.S in the 1940s and has since spread throughout much of the country. This submersed aquatic plant can form dense mats at the water surface limiting access, recreation, and aesthetics and thus, has decreased the values of shoreline properties in New Hampshire, the Midwest and elsewhere (Halstead et al. 2003).

Decreased Sport Fishing Opportunities

Whirling disease is caused by a parasite (*Myxobolus cerebralis*) that most likely originated in Europe. It was first observed in the U.S. in 1958. The parasite attacks the soft cartilage of young trout causing spinal deformities and causes the fish to exhibit erratic tail-chasing behavior. Heavily infected young trout can die from whirling disease and even if they recover, they remain carriers of the parasite. All species of trout and salmon may be susceptible and angling and the businesses supported by trout and salmon fishing may be at risk if this disease continues to spread (Aquatic Nuisance Species Task Force et al. 2005; Colorado Division of Wildlife 2006).

Smallmouth bass fishing in Lake Erie was closed during bass mating because of round goby predation of nests. Fishing was closed because male smallmouth bass aggressively guard nests from predators and are easier to catch by anglers during this time of year. Removal of males by anglers decreased the number of bass offspring because of increased round goby predation of unguarded nests (Steinhart et al. 2004). Businesses that smallmouth bass anglers patronize could be adversely affected by such closures.

Altered Business Opportunities

The concern over sudden oak death syndrome caused by the pathogen *Phytophthora ramorum* is causing drastic changes in available nursery stock by nurseries and landscape businesses. This clearly impacts the profitability of these businesses and choice by consumers and could devastate oak forests nationwide (Chornesky et al. 2005; Rizzo and Garbelotto 2003).

Annual harvests of oysters in Long Island Sound averaged over 680,000 bushels during 1991 through 1996. After *Hap-*

losporidium nelsonii (MSX) invaded in 1997 and 1998, oyster harvests decreased from 1997 through 2002 to an average annual harvest of 119,000 bushels with a low of 32,000 bushels in 2002. The overall ex-vessel value of oyster farming dropped 96% in ten years from $45 million in 1992 to $2 million in 2002 (Sunila et al. 1999).

Non-native algae introduced into the Hawaiian Islands costs Maui alone about $20 million annually due to algae fouling the beaches and subsequent lost tourism (Carroll 2004; Keeney 2004; Univ. Hawaii 2006).

Sea lampreys were introduced into Lakes Ontario and Erie during the construction of the Welland Canal and quickly spread to the other Great Lakes. The sea lamprey is a parasite that attaches itself to fish, eventually killing them, and has devastated commercial and recreational lake trout fishing in the Great Lakes (Lawrie 1970).

Australian spotted jellyfish were introduced into the Gulf of Mexico in 2000 and occurred in such massive numbers that shrimping operations were shut down because jellyfish clogged shrimp nets (Graham et al. 2003).

Altered Ecosystems and Recreational Opportunities

The submersed aquatic plant *hydrilla,* forms dense canopies at the water surface that raise surface water temperatures, change pH, exclude light, and consume oxygen, resulting in native plant displacement and stunted sport fish populations. This example of an altered aquatic ecosystem caused by an invasive aquatic weed also negatively affects recreation and businesses that depend upon that human activity (Colle et al. 1987).

SUMMARY

Invasive species are those that are not native to the ecosystem under consideration and that cause or are likely to cause economic or environmental harm or harm to human, animal, or plant health. Plant and animal species under domestication or cultivation and under human control are not invasive species. Furthermore for policy purposes, to be considered invasive, the negative impacts caused by a non-native species will be deemed to outweigh the beneficial effects it provides. Finally, a non-native species might be considered invasive in one region but not in another. Whether or not a species is considered an invasive species depends largely on human values. By attempting to manage invasive species, we are affirming our economic and environmental values. Those non-native species judged to cause overall economic or environmental harm or harm to human health may be considered invasive, even if they yield some beneficial effects. Society struggles to determine the appropriate course of action in such cases, but in a democratic society that struggle is essential.

Many invasive species are examples of "the tragedy of the commons," or how actions that benefit one individual's use of resources may negatively impact others and result in a significant overall increase in damage to the economy, the environment, or public health. In ISAC's review of Executive Order 13112, the public domain is specifically represented; however, the implementation of the Management Plan has prompted concerns over the rights of personal and private property owners. Property rights are of great importance in the U.S. and one outcome of the Management Plan should be to recognize the right to self-determination by property owners and promote collaboration on invasive species management. The right to self-determination is an important concept in a democratic society, however, with that right comes personal responsibility and stewardship, which includes being environmentally responsible. The natural environment that our society enjoys, recreates in, and depends upon to support commerce must be conserved and maintained. Effective invasive species management is just one aspect of conserving and maintaining our nation's natural environment, the economies it supports, and the high quality of life our society enjoys.

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ISAC
INVASIVE SPECIES ADVISORY COMMITTEE

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Biofuels: Cultivating Energy, not Invasive Species

Approved by ISAC on August 11, 2009

ISSUE

To provide alternatives to petroleum-based energy, the United States (U.S.) government has mandated a greater proportion of plant-based biofuels be integrated into its energy portfolio. However, *certain plant species being proposed for biofuel production in the U.S. are invasive species or are likely to escape cultivation and become invasive.*

U.S. Executive Order (E.O.) 13112[1] defines invasive species as "alien [non-native] species whose introduction does or is likely to cause economic or environmental harm or harm to human health" and states:

> "Each Federal agency whose actions may affect the status of invasive species shall, to the extent practicable and permitted by law… not authorize, fund, or carry out actions that it believes are likely to cause or promote the introduction or spread of invasive species in the United States or elsewhere unless, pursuant to guidelines that it has prescribed, the agency has determined and made public its determination that the benefits of such actions clearly outweigh the potential harm caused by invasive species; and that all feasible and prudent measures to minimize risk of harm will be taken in conjunction with the actions."

The socio-economic and ecological costs of certain biofuel crops could greatly exceed their benefits. Thus, the Federal government needs to take strategic action to avoid inadvertently facilitating the introduction and spread of invasive species through its development, encouragement, funding, or other support of biofuels programs.

ACTION

This briefing paper, adopted by the U.S. Invasive Species Advisory Committee (ISAC) on August 11, 2009, provides:

a) background information on the potential linkages between biofuels and invasive species and;
b) recommendations for Federal action to reduce the risk of invasive species introduction and spread through its biofuels programs. Implementation of these recommendations will help to ensure that the U.S. maximizes the benefits of its biofuel initiatives while preventing the spread of invasive species.

BACKGROUND

Agency Roles and Responsibilities

Depending on their mission, Federal agencies might engage in biofuel programs by:

- conducting biofuel research and development;
- introducing and producing biofuel crops for experimentation and/or use;
- subsidizing biofuel research, development, production, and marketing;
- purchasing biofuels to supplement their energy demands;
- establishing early detection and rapid response programs for escaped biofuel plants;
- implementing long-term management of biofuel crops that become invasive, and/or regulating various aspects of the biofuels pathway, when necessary.

Policy and Legal Responsibilities

Specific agency directives for biofuel programs are emerging in Federal legislation. For example, the 2007 Energy Independence and Security Act (EISA) mandates the production of 61 billion liters of plant cellulosic-based fuels. This cannot be met with current agricultural, forestry, and municipal residues alone. It necessitates large-scale planting of dedicated energy crops that do not compete with food or feed. This will require producing and promoting biofuel crops for experimentation and demonstration. The U.S. Department

1 www.invasivespecies.gov (see E.O. 13112 and the ISAC Definitions White Paper)

Box 1.
Economic Impact of
Invasive Plants in the U. S.[1]

Estimated losses and the cost of control is $34 billion annually.

- $26.4 billion on agricultural invasives
- $6 billion on pasture invasives
- $1.5 billion on turf and garden invasives
- $0.1 billion on aquatic invasives

1 Pimentel et al. 2000. *BioScience* 50:53-65.
Note: Paper largely addressed managed systems. Additional research is needed for natural areas.

of Agriculture's (USDA) research effort is therefore focused on identifying crops that will maximize yield while allowing cultivation on less productive, marginal lands with minimal agricultural inputs. The Food, Conservation, and Energy Act of 2008 (i.e., 2008 U.S. Farm Bill PL 110-234) also directs USDA to provide subsidies for growers to encourage adoption of dedicated energy crops which currently do not have a market. The 2008 Energy Act directs the U.S. Environmental Protection Agency (EPA), in consultation with USDA and the Department of Energy (DOE), to report to Congress on the environmental and resource conservation impacts of biofuels (first report due Dec.2010).

Invasive Species Risk

This paper focuses on one potential negative impact of biofuels, namely the risk that they will escape cultivation and become invasive species. Although most of our food, fiber, and landscape plants are non-native species and relatively few have proven invasive, those that are harmful have caused substantial socio-economic and environmental impacts (e.g., johnsongrass [*Sorghum halepense*] and kudzu [*Pueraria montana*])(Box 1). A number of potentially harmful non-native algal species are being considered for use in the production of biodiesel, renewable biodiesel, and jet fuel (e.g., the toxic freshwater cyanobacteria, *Anabaena circinalis*). (First report due December 2010).

Indications that some biofuel crops pose a particular risk of becoming invasive include:

- Certain plant species proposed for biofuel production (e.g., reed canarygrass [*Phalaris arundinacea*], giant reed [*Arundo donax*], and miscanthus [*Miscanthus sinensis*]) are already invasive in regions of the U.S. and/or elsewhere in the world.
- Several of the traits that could maximize biofuel crop yield and foster the ability for biofuels to be cultivated in marginal environments can also increase risk of invasiveness. Invasive plants share many of the traits desired in biofuel crops and these traits may allow them to grow on marginal lands (Box 2).
- The potential scale of biofuel cultivation (>61 million ha) suggests ample opportunity for biofuel crops to be introduced into environments in which they could thrive and interact with ecosystems.

Box 2.
Traits that Maximize Crop Yield and
Increase Risk of Invasiveness

- Perennial growth form
- Rapid and high aboveground biomass production
- Tolerance of drought, low fertility, or saline soils
- Highly competitive with other vegetation
- Few resident pathogen or insect pests

Absent strategic mitigation efforts, there is substantial risk that some biofuel crops will escape cultivation and cause socio-economic and/or ecological harm. If invasion occurs, the costs associated with the damage may negate the economic benefits conveyed by cultivation of the particular species. The risks are particularly significant where biofuel crops are cultivated within ecosystems that include forest, prairie, desert, and wetland areas, as well as rangelands and other agricultural croplands.

RISK MITIGATION AND RECOMMENDATIONS

To minimize the risk of biofuel crop escape into the surrounding environment, the U.S. government needs to employ and promote ecological studies and scientific models that characterize the invasion risk of each biofuel species or cultivar (as appropriate) within a target region and identify ecosystems most susceptible to invasion. Information generated from biofuel crop ecological studies, risk analyses, bioeconomic and climate match modeling, and other methods can guide the government's risk mitigation plans. Depending on their authorities, Federal agencies can take strategic steps at appropriate points within research and development, crop production, harvest and transportation, conversion/refinery practices, and/or regulatory action to minimize the risk of biofuel crops becoming invasive. ISAC recommends that the Federal government apply the following recommendations to its own biofuels programs, as well as use them as a basis for standards of operation when engaging with the private sector and other partners.

1. Review/Strengthen Existing Authorities

Identify Federal authorities relevant to biofuels. Determine their likely influence on biofuel invasiveness (i.e., prevention or facilitation). Identify gaps and inconsistencies in authorities within and among Federal Departments or Agencies. As appropriate, develop policies and programs to minimize invasion risk.

2. Reduce Escape Risks

In order to determine potential biofuel benefits and risks, the invasive potential of each candidate biofuel crop needs to be evaluated in the context of each region proposed for its production. Use/promote species (including unique genotypes) that are not currently invasive and are unlikely to become invasive in the target region. Choose species or cultivars with a low potential for escape, establishment and negative impact. Where appropriate, implement mitigation strategies and plans to minimize escape and other risks.

3. Determine the Most Appropriate Areas for Cultivation

Ideally, biofuel crops should be propagated in containable systems (e.g., terrestrial or aquatic sites constructed specifically to cultivate biofuel crops) and be unable to survive outside of cultivation. Use research findings to identify the most appropriate sites (e.g., unlikely to impact sensitive habitat or create disturbances that will foster invasion) for cultivation of biofuel crops within landscapes. Support for biofuel research and demonstration projects will require site selection that minimizes the potential escape of plant species or cultivars to sensitive areas and the loss of wildlife habitat.

4. Identify Plant Traits that Contribute to or Avoid Invasiveness

Incorporate desirable traits (e.g., sterility or reduced seed production, inability to regenerate by stem fragments) into biofuel varieties to minimize their potential for invasiveness. Use information from plant research, agronomic models, and risk analyses to guide breeding, genetic engineering, and variety selection programs.

5. Prevent Dispersal

Develop and coordinate dispersal mitigation protocols prior to cultivation of biofuel plants in each region or ecosystem of consideration. Implement a comprehensive plan, appropriate to the specific crop, throughout the cultivation period. Examples of dispersal mitigation measures include the use of sterile cultivars, species not likely to genetically mix with other plants (different species or cultivars), harvesting prior to seed maturity, cleaning equipment, and minimizing propagule dispersal throughout the biofuel production cycle.

6. Establish Eradication Protocols for Rotational Systems or Abandoned Populations

Proactively develop multiple year eradication protocols to plan for the rapid removal of biofuel crops if they disperse into surrounding areas or become abandoned or unwanted populations (e.g., those which persist beyond desired crop rotation period).

7. Develop and Implement Early Detection and Rapid Response (EDRR) Plans and Rapid Response Funding

Develop EDRR plans that cover multiple years to eliminate or prevent establishment and spread of escaped invasive populations. A flexible funding source needs to be in place to support EDRR efforts.

8. Minimize Harvest Disturbance

Disturbed environments are especially prone to plant invasion. Minimize the soil disturbance resulting from biofuel harvest by rapidly replanting, using cover crops, or employing other methods that will prevent the potential for future invasion of non-native plants from the surrounding area into the harvested site.

9. Engage Stakeholders

Identify and employ cooperative networks (e.g., working groups and councils), communication forums, and consultation processes through which the Federal agencies can work with state agencies, tribes, the private sector, and other stakeholders to reduce the risk of biological invasion via the biofuels pathway.

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Invasive Species and Public Investment in the Green Economy

Approved by ISAC on June 24, 2010

ISSUE

Invasive species are intricately linked to the economy. Trade, travel, and transport facilitate their spread. Invasive species management requires extensive human and financial resources. The impacts of invasive species can substantially undermine economic growth and sustainable development.

U.S. Executive Order (E.O.) 13112 defines invasive species as "alien [non-native] species whose introduction does or is likely to cause economic or environmental harm or harm to human health" and states that Federal agencies should…"not authorize, fund, or carry out actions that are likely to cause or promote the introduction or spread of invasive species…"

The Obama Administration and the 111th Congress have identified expansion of the Green Economy—an emerging marketplace that seeks to optimize the synergy among social, environmental, and financial values[1]—as a top priority.[2]

Invasive species prevention and management[3] can foster the Green Economy through green collar job creation and social development programs. On the other hand, if invasive species are not addressed as a matter of urgency, their spread and consequent impacts will substantially undermine green economic growth,[4] including our capacity for renewable energy development/expansion.[5]

DECISIVE ACTION IS REQUIRED

This briefing paper, adopted by the U.S. Invasive Species Advisory Committee (ISAC), provides:

a) Background information on the linkages between invasive species and the Green Economy, and;

b) Recommendations for action by the Federal government to capitalize on the opportunities invasive species prevention and management provide for *green collar jobs and social program development*, as well as to *reduce the risks that invasive species pose* to realization of green economic growth.

BACKGROUND

Opportunities

The prevention and management of invasive species requires substantial human resources across a wide range of expertise, including inspection, taxonomic identification, research, monitoring, education and communication, technical assistance, policy and regulation, control, eradication, and restoration. In addition to jobs created specifically to address invasive species, the technical demands of invasive species prevention and management expand job opportunities across a wide variety of sectors (e.g., software development for mapping and modeling, development and testing of tools for integrated pest management). The need for green collar jobs ranges from entry level to highly technical. Entry-mid level positions could be designed to serve as technical training and social development programs for youth and persons at risk, providing benefits well beyond the management of invasive species. For example, South Africa's Working for Water Programme employs approximately 29,000 workers (mostly impoverished women) per year. In addition to salary (starting at $6USD/day), they receive health care, child care, and educational benefits. The service the workers provide to the region is substantial; eradication and control of some 200 invasive plant species, which clog waterways, degrade farmland, heighten fire risk, decrease water supply, and contribute to desertification. Secondary industries provide economic development opportunities by turning some of the invasive plants into products such as baskets and school desks (Koenig 2009).[6]

1 A.K.A. "The Triple Bottomline"
2 e.g., bills S. 267–269; www.govtrack.us/congress and www.whitehouse.gov/issues/energy-and-environment
3 For the purposes of this paper, management means both eradication and control measures.
4 Invasive species already cost the U.S. more than $100 billion/year (Pimentel et al. 2000)
5 For more information, see ISAC briefing paper, "Biofuels: Cultivating Energy, not Invasive Species;" www.invasivespecies.gov
6 See also Republic of South Africa Department of Water Affairs and Forestry's Working for Water program: https://intertest.dwa.gov.za/wfw/default.asp.

Challenges

Invasive species can pose substantial threats to natural resources and, in turn, green economic growth. Forestry, aquaculture, horticulture, and farming are all vulnerable to the impacts of invasive species. In Ohio alone, the impact of the emerald ash borer[7] on community residents is estimated to be between $1.8 and $7.6 billion for tree loss, removal, and replacement (Sydnor et al. 2007). Invasive plants have reduced the real estate value of Montana's ranches by nearly 60% (Sheley et al. 2005). The glassy winged sharpshooter[8] poses an economic threat to California grape, raisin, and wine industries, as well as associated tourism, collectively amounting to nearly $35 billion annually (National Agricultural Library). Invasive species also impact recreational opportunities such as hunting, fishing, and gardening, which create substantial revenue for state and local governments. In the western U.S., deer and elk have lost native forage (up to 90%) to invasive plants, and throughout the country waterfowl habitat is degraded by aquatic invaders (e.g., purple loosestrife and tamarisk) (U.S. Forest Service, National Agricultural Library). The economic impacts of invasive species on these sectors can result in decreases in profitability, job loss, and even business failure.

Emerging green markets, such as renewable energy, need to guard against the potential negative economic impacts of invasive species. For example, creation of "energy farms" and "energy corridors" will disturb landscapes, increasing opportunities for the establishment and spread of invasive plants which could become a costly, long-term site-maintenance requirement. Some species of proposed biofuels are known to be invasive or have the potential to become invasive. Under these circumstances, the costs to society may substantially outweigh the benefits of using these non-native organisms. To prevent the establishment and spread of invasive species via energy sector activities, early detection and rapid response programs will need to be well staffed and funded.[9]

RECOMMENDATIONS

We call on the member Departments and Agencies of the National Invasive Species Council (NISC) and potential partners to:

1. Establish a national survey of invasive species, to be administered at the state-level. Support this program by substantially increasing Federal and state jobs at all technical levels to survey, identify, map, catalog, and model patterns/trends of invasive plants and animals.[10] Include the existing state and regional invasive species committees/councils in the development and implementation process. Place priority on invasive species known or projected to have substantial impacts.
2. Supplement the Federal and state workforce by creating contract jobs in the private sector and offering grants to encourage business innovation and entrepreneurship (e.g., native plant and seed companies, ecosystem restoration, invasive species mapping and control services, and education/outreach programs).
3. In order to counter the dramatic decline in taxonomic capacity (i.e. the decrease in the number of people trained to identify specific species), provide grants to support research/education/training in taxonomy as well as job creation for taxonomists and parataxonomists (people who lack formal higher-level education, but who are trained to undertake species identification tasks).
4. Capitalize invasive species prevention and management needs (e.g., along roadways and on government lands) to create entry–mid level, high impact social development programs for youth and persons at risk (e.g., minimum security prison population). Establish Federal initiatives and/or offer grants to states and tribes.
5. Substantially increase Federal and state agency staffing in the areas of import/border inspection for agriculture and wildlife (Reaser and Waugh 2007), specimen identification, pest risk analysis (including pre-import screening), and invasive species program management (esp. public education/outreach, regulatory enforcement, and early detection/rapid response).
6. Establish/strengthen internships in invasive species identification, control/eradication, mapping, and monitoring for high school and college students. Support comparable Federal, state, tribal, and non-profit initiatives.[11]
7. Develop stronger relationships between the Federal government and green industries potentially impacted by and/or managing invasive species. For example, work with the Invasive Species Advisory Committee (ISAC) and/or NISAW to organize an Invasive Species & Green Industries Summit.
8. Mandate that, prior to receiving Federal support: 1) renewable energy projects (esp. solar, wind, and biofuel) have adequate invasive species mitigation plans in place and 2) biofuel developers/producers demonstrate that non-native species are of low invasion risk (to the propagation site, area of potential dispersal, and along transport pathways) based on a competent invasive species risk analysis.[12]

7 A small insect native to eastern Asia.

8 Found relatively recently in California, an invasive insect which carries a deadly plant bacterium, *Xylella fastidiosa*.

9 For more information, see ISAC briefing paper, "Biofuels: Cultivating Energy, not Invasive Species;" www.invasivespecies.gov.

10 In implementing this recommendation, capitalize on the mapping (etc.) that has already been accomplished.

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11 For example, the Youth Conservation Corps and the Student Conservation Association.

12 For more information, see ISAC briefing paper, "Biofuels: Cultivating Energy, not Invasive Species;" www.invasivespecies.gov.

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Invasive Species and Climate Change

Approved by ISAC on December 9, 2010

ISSUE

Climate change interacts with and can often amplify the negative impacts of invasive species.

These interactions are not fully appreciated or understood. They can result in threats to critical ecosystem functions on which our food system and other essential provisions and services depend as well as increase threats to human health. The Invasive Species Advisory Committee to the National Invasive Species Council recognizes the Administration's commitment to dealing proactively with global climate change. However, unless we recognize and act on the impact of climate change and its interaction with ecosystems and invasive species, we will fall further behind in our effort to prevent, eradicate, and manage invasive species. We are already seeing such climate change impacts and need to act now.

DECISIVE ACTION IS REQUIRED

Policy makers at all levels of government must integrate invasive species considerations into climate change policies. The strong interrelationships between climate change and the dynamic nature of invasive species, changing ecosystems, and human activities necessitate such integration. It is critical that practices be developed that strengthen environmental monitoring, management, and control of invasive species to minimize impacts on the broad range of ecosystem resources upon which humans depend. The physical process of climate change interacts with the biological and physical processes of the earth's ecosystems, and these are, in turn, linked to the socio-economics of human activities.

BACKGROUND

Climate change and biological invasions are dynamic, interconnected and interdependent phenomena. They affect human health and well-being through their impact on resources, goods and services provided by ecosystems. These ecosystems are critical to agriculture and forests, food security, water supplies and other natural resources. They affect wildlife, recreation, and public health and safety nationwide. Even without climate change, invasive species have repeatedly and rapidly disrupted many ecosystems in the U.S. While climate change may have either a positive or negative effect on individual invasive species, which can be projected in various models, it is likely to have a negative effect on many specialist native species that are more restricted in their ranges. Invasive species often show higher ability to acclimate to environmental change compared to related native species. Thus, invasive species that tend to be more adaptable are expected to expand and further compromise sensitive native plant and animal communities.

The ongoing change in climate and the expected speed of this change are likely to exacerbate problems by increasing the ability of invasive species to become established, spread through, and disrupt ecosystems. At a minimum, invasive species can reshuffle the landscape for agricultural services and resources including food, fuel, feed, fiber, and forests along with quickly changing land-use decision pressures. As a parallel, in marine and/or aquatic ecosystems, climate change can induce fisheries collapse as mid-trophic structure species are lost opening new potential niches for tolerant invasive species. Finally, climate induced shifts in invasive disease vectors, such as those for malaria or avian flu, are of increasing concern.

Evidence indicates that climate change may alter the efficacy of management strategies for invasive species. Furthermore, changes in land cover caused by invasive plants can influence weather and climate. In some regions, both climate change and invasive species are likely to increase the frequency of wildfires which in turn will further facilitate the establishment of fire adapted invasive species leading to even more frequent and intensive fires.

RECOMMENDATIONS

Policy and Legal Responsibilities

We applaud the U.S. Department of Interior's establishment of a Climate Change Response Council to synthesize data and coordinate appropriate management of our nation's lands and waters. We acknowledge the U.S. Department of Agriculture's (USDA) recent presentation of the impact of climate change in its publication: "*Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States.*" We fully support the Department of Commerce's National Oceanographic and Atmospheric Administration's (NOAA) proposal to establish the NOAA Climate Service to meet essential national needs.

Executive Order 13112 requires Federal agencies to address invasive species and establishes the National Invasive Species Council to coordinate planning and response. The International Plant Protection Convention requires analyses of pest risk. Agencies may be able to integrate climate change considerations into their existing risk-assessment protocols and procedures. Environmental laws such as the Endangered Species Act and the National Environmental Protection Act (NEPA) can be used more powerfully to address invasive species.

Opportunities for Action

We call on the member Departments and Agencies of the National Invasive Species Council and potential partners to:

1. *Use the Global Change Research Act of 1990* (GCRA)48 (PL 101-606) to aggregate information about the implications of a changing climate for invasive species spread so scientific data may be synthesized through existing authorities to inform policy-makers.
2. *Streamline and focus agency programs* to address invasive species climate interactions effectively and efficiently by establishing: 1) strategic plans that anticipate climate impacts on invasives, 2) forward-looking environmental compliance documents (e.g., NEPA, nationwide Environmental Impact Statements on invasives prevention, management, and restoration), and 3) focus awareness programs to anticipate and manage potential climate driven ecosystem changes.
3. *Assess new climate driven invasion pathways and strengthen prevention programs* to address invasives in ballast water, bio-fouling, interstate and international movement of materials and equipment (e.g., energy development, wildfire response, national defense), and screening of plant and animal imports taking account of climate impacts.
4. *Support monitoring and adaptive management programs* for invasive species at the landscape scale so that natural resource managers can identify new threats and respond quickly and appropriately to invasive species in changing climatic conditions.
5. *Foster collaboration of existing networks* to address the broad geographic nature and altered management of invasive species issues in a time of climate change. This will allow the national response to be coordinated, efficient, and capitalize on current capacities using a synergistic approach.
6. *Increase research and development* targeted at climate change and invasive species by supporting and expanding the USDA-ARS and U.S. Forest Service Climate Change Programs, as well as competitive research programs such as USDA's Agricultural and Food Research Initiative, the Environmental Protection Agency's Project Grants, National Science Foundation's Conservation and Biology program, and NOAA's Sea Grant program. Better understanding of the interaction of climate change and invasive species will result in more relevant prioritization and management on the ground. This includes recognizing the economic basis for invasive species management decisions and supporting work that integrates economic, ecological, and biological data providing policy and management support.
7. *Use climate matching and ecological niche models* to prioritize management of species that are most likely to cause the greatest harm in the future as a result of climate change.

This will require the Federal response to be coordinated, empowered, and appropriately funded.

ISAC
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Marine Bioinvasions and Climate Change

Approved by ISAC on June 24, 2010

ISSUE

No ocean area is unaffected by human impact (Halpern et al. 2008). Marine bioinvasions are one of the greatest threats from human activity on this environment (Carlton 1996). However, our knowledge of the impacts of invasions is severely lacking for many key regions of the country and the world, and very little is known of the impacts from invasive species in relation to climate change (Sorte et al. 2010). Environmental consequences may include loss of marine biodiversity as oceans freshen, warm, and sea level rises. Additional impacts to native communities may occur as a result of ocean acidification and/or changing current and wind patterns.

An overall warming between 2.0 and 4.5° C is predicted in the next century as a result of global climate change (Solomon et al. 2007). This shift in temperature will affect marine ecosystems by raising water temperatures, decreasing oceanic pH, altering stream flow patterns, increasing storm events, and contributing to sea level rise. These changes are expected to have a substantial impact on the abundance and distribution of marine species as well ecosystem functioning and food webs. The Intergovernmental Panel on Climate Change (IPCC) has confirmed that range shifts among marine flora and fauna have already begun to occur in response to warming trends and include poleward and elevational shifts (Solomon et al. 2007).

Non-native species are those that evolved elsewhere and have been transported by natural processes or human activities, either intentionally or accidentally, into a new region. Invasive species are the subset of introduced species that persist, reproduce, and spread rapidly into new locations, causing economic or ecosystem harm or harm to human health (Williams and Smith 2007).

Invasive species share traits that may allow them to capitalize on the impacts of global climate change including fast growth, rapid reproduction, and the ability to survive in a wide range of environmental conditions.

Further, spcies that have long been "in motion," but were failed invasions as a result of too-cold waters, will now likely invade these once "off limits" thermal regimes (Solomon et al. 2007). Consequently, a decline in cold-affinity or even "typical" resident species and an increase in warm-affinity residents can be expected, which will change species proportions as well as community structure and dynamics.

An estimated 10,000 marine species are transported around the world in ballast water *every day* (Carlton 1999). Biological invasions will be further aided by global climate change through increased dispersal of non-native species via ballast and hull fouling resulting from changes in maritime or recreational routes. Other consequences of global climate change may include increased diseases (Lawrence 2008), increased loss of calcified species from ocean acidification, opening of new habitat via inundation with increased disturbance to existing habitat from increased pollution and terrestrial runoff (Doney et al. 2009). Synergies among all of these processes are most likely. These outcomes will result in the decline of native species, create open space, and deliver new invasive competitors to habitats once held off limits by natural processes.

BACKGROUND

Invasive species are second only to habitat destruction as the greatest cause of species endangerment and global biodiversity loss. Invasive species can cause severe and permanent damage to the ecosystems they invade. Consequences of invasion include competition with or predation upon native species, hybridization, carrying or supporting harmful pathogens and parasites that may affect wildlife and human health, disturbing ecosystem function through alteration of food webs and nutrient recycling rates, acting as ecosystem engineers and altering habitat structure, and degradation of the aesthetic quality of our natural resources. In many cases we may not fully know the native animals and plants in an area. For example, *Aureophycus aleuticus,* a large kelp was just described with similar discoveries of new taxa in many other latitudes. Invasive species have the potential to permanently change ecosystems before we fully understand the native communities.

Recent studies suggest that invasive species share similar traits that allow for easier establishment in habitats that become disrupted by climate change. The examples below highlight some of the ongoing and expected changes to marine ecosystems that may occur as a result of the interactions between global climate change and biological invasion.

Sea Level Rise

Sea level rise has been estimated at 3.1 ± 0.7 mm yr-1 as a result of thermal expansion of water and the melting of continental ice sheets (Williams and Smith 2007). A rise in sea level of less than 1 m would submerge an estimated 10,000 square miles of land (Titus 1989). Existing wetland and salt marshes will be flooded and die, calling into question the types of communities that will replace these lost ecosystems.

Inundation could also disrupt groundwater flow from aquifers to ocean by altering the water table level relative to the sea level, potentially diminishing the delivery of essential nutrients to at least, tropical reef communities and disrupting coastal wetlands (Titus 1989). Native marine species will likely be subjected to increased turbidity and pollution resulting from runoff from the land. Although some native species will be able to adapt to the newly created habitats, the high level of disturbance caused by sea level rise will render marine communities particularly vulnerable to the introduction of opportunistic invasive species.

Increased Ocean Temperatures

Since 1961, ocean temperatures have risen 0.10° C from the surface to a depth of 700 m (Williams and Smith 2007). Warmer water conditions may facilitate the successful establishment of invasive species adapted to warmer environments. Such species may prey on or compete for food resources with native species, possibly leading to extinction unless the native species are able to find refuge at higher latitudes. Many regions have already experienced the impacts of warming coastal waters, demonstrating an alteration in species ranges. This alteration includes an expansion of organisms tolerant to warm waters, thus migrating poleward, and a reduction in ranges of cold water species, thus shrinking poleward (Solomon et al. 2007). For example, tropical algae have already successfully invaded now-warmer temperate locations and it is expected that tropical-to-temperate algal invasions may become more common. Some temperate invasive algae have been noted to become less seasonal and are now reproducing all year round whereas in their native ranges they have retained much stronger seasonality.

Increased ocean temperatures may result in the extinction of several species, which may lead to a complete alteration of ecosystems. For example, a shift in ocean temperatures by as little as 1° C above the maximum monthly mean results in coral bleaching, which negatively impacts the entire coral reef ecosystem. Animals, plants, and seagrasses that rely on the low-lying habitat provided by coral reefs are likely to be significantly affected, although these potential impacts are just beginning to be explored. Loss of coral will likely create open spaces, rendering the ecosystem vulnerable to invasion. Some invasive seaweeds are not as thermally sensitive as corals (Smith et al. 2004), thus warmer ocean temperatures may set a stage for these "weedy" species to thrive.

Changes to Salinity

Salinity trends are characterized by decreased salinity in oceans within subpolar latitudes whereas shallower waters of the tropical and subtropical oceans have shown increased salinity levels. Freshening is pronounced in the Pacific Ocean while increased salinity is found in the Atlantic and Indian Oceans. These trends are consistent with changes in precipitation that are a possible consequence of global climate change (Williams and Smith 2007).

Major shifts in the abiotic environment will result in a change in the existing species composition as there will be some organisms that will be unable to adapt to their new environment; therefore these species will be forced to disperse to adjacent habitats or become extinct. This loss of biodiversity may facilitate the establishment of new weedy / invasive species that are able to thrive in the changing environment.

Successful invasion may also be assisted by a change in the vectors responsible for introduction. For example, ballast water has been a major transport carrier for invasive species since the late 20th century as a result of the increased scale of global trade. This increase has encouraged the need for larger ships, traveling at faster speeds. As open water exchange is the most common ballast management practice used today, increased salinity in coastal waters may enhance the probability of survival of propagules in ballast water. Higher survival rates will increase the probable number of individuals released at a given place at a given time as well as the number of transported organisms that are capable of survival and reproduction following release.

Ocean Acidification

Uptake of atmospheric carbon dioxide by the oceans has already lowered the pH of coastal waters in urbanized regions and is expected to substantially lower oceanic pH over the next decades. The increase in total inorganic carbon causes a decrease in the depth at which calcium carbonate dissolves, causing a decrease in surface ocean pH (Williams and Smith 2007).

In tropical regions, entire (non-living) calcareous reef structures are at risk (Doney et al. 2009). In terms of the food web for these ecosystems, all organisms that photosynthesize, phytoplankton and seaweeds, will be impacted via changed concentrations and species of carbon for photosynthesis. Further, acidification directly harms the ocean's plants and animals that build shells composed of calcium carbonate. Calcifying species include corals, mollusks, crustaceans, and coralline algae that provide critical habitat and food sources for other organisms. Declining number and/or abundances of these species may promote the success of existing invaders or the colonization of new invaders—namely fleshy/non-calcified algae. The introduction of competitive non-native species into an ecosystem may have a substantial, and often irreversible, influence on biodiversity, habitat quality, and ecosystem functioning.

Change in Ocean Circulation and Currents

Decreased upwelling due to warmer waters will result in fewer nutrients being transported from deep in the water column to the water surface (Williams and Smith 2007). The productivity of marine ecosystems will be reduced as these areas depend on the delivery of nutrients from upwelling areas and ocean currents. Species that depend on ocean currents for reproduction and migration will also be affected. For example, many coral and fish species rely on dispersal of their larvae by currents; therefore, changes in circulation will result in lower recruitment into new areas, reducing species dispersal as well as overall habitat diversity. The disruption of recruitment could facilitate the establishment of invasive species as newly opened areas will be vulnerable to the introduction of these opportunistic species.

Evidence that Change has Already Occurred

There is evidence that some marine species have already responded to climate change. For example, in 1999 the marine diatom, *Neodenticula seminae*, was found in the Atlantic Ocean during routine plankton surveys (Reid et al. 2007). This diatom migrated from the North Pacific to the Atlantic Ocean as a result of the diminishing ice cover in the Arctic which opened up a temporary passageway between the Arctic and Pacific Oceans. The presence of the diatom in the North Atlantic, establishing itself in areas where it was last found during the Pleistocene, indicates a change in the circulation between the North Pacific and North Atlantic oceans as a response to the major climatic and oceanographic changes that have taken place in the Arctic in recent years (Reid et al. 2007). As sea ice diminishes, we will continue to see changes in the distribution, composition and abundance of algal species. Algae are the foundation of most of Arctic trophodynamics, and thus these changes will produce a cascading effect through the food web.

Range shifts are defined as changes in the distribution of native species that are not directly human mediated. As a result of global climate change, many species will migrate to maintain the temperature conditions needed for reproduction, growth, and feeding. There is a growing concern that these shifting species will begin to function as invasive species, disrupting the structure and function of their new community. Over 100 marine range shifts have already been documented; these cases are likely only a fraction of the marine species that have moved or are in the process of moving (Solomon et al. 2007). This trend, illustrated in the examples below, has been seen in a broad range of taxa including algae, bryozoans, cnidarians, crustaceans, and mollusks:

- *Caulerpa taxifolia*, the "killer algae," is a tropical seaweed that has already been able to invade temperate regions. This algal species has rapidly colonized the Mediterranean, where it covers the bottom and fills the water column with hundreds of tons of plant biomass per hectare. Infestations in California took 6 years and over $7M to eradicate. With warming seas around many temperate coastlines, *Caulerpa* invasions may become more common.
- The Pacific Lionfish *(Pterois volitans)* was first detected in Florida in 1990s and is now common off the Carolinas. As of 2009, the tropical fish was found as far north as Cape Cod during the summer months. Warming conditions probably will permanently expand the range of this fish along much of the eastern coast of the United States. The broad diet of the lionfish suggests that this invasive species may become a real threat to many native reef fish populations through direct predation as well as competition for food resources with native piscivores. Further, its voracious feeding behavior may impact the abundance of ecologically important species such as herbivorous fishes that keep seaweeds and macroalgae from overgrowing corals.
- "Caribbean Creep" is defined by the invasion of Georgia, the Carolinas, and Chesapeake Bay by tropical and subtropical species. Species that have successfully invaded these temperate areas include the Brazilian green porcelain crab (*Petrolisthes armatus),* Florida rocksnail *(Stramonita haemastoma*), the Indian caprellid crustacean (*Caprella scaura*)*,* and the Asian-Pacific Titan acorn barnacle (*Megabalanus coccopoma*). These are not one-off occurrences of individuals of southern species; these examples represent permanently established populations of species that previously found the South Atlantic Bight and Chesapeake Bay too cold to live in.
- The New Zealand pillbug, *Sphaeroma quoianum*, invaded Oregon in the 1990's. This isopod crustacean creates burrows within banks composed of mud, clay, or peat. The system of interconnected burrows within the banks has led to an increase in erosion rates by as much as 250% in many estuarine environments. The burrows also damage docks, wooden structures, levees and dikes. The invasion into substances such as Styrofoam can disperse microscopic polystyrene particles into local waterways; 100,000 isopods in a Styrofoam float release more than 20,000,000 styrene particles per day into the ocean.

RECOMMENDATIONS

Changes in the Earth's climate will likely continue, or even accelerate, over the next century. The economic, energy, social, and environmental impacts of invasions mediated by climate change may be profound. Our understanding of climate-driven species movements is only the tip of the iceberg: a great many more species are in motion. Predictions of how species and their habitats will respond to climate change will assist in making conservation decisions and managing our natural resources. Invasive species management will need to develop tools that include both invasion biology and climate change impacts. The following are recommendations to assist the development of such tools:

Fund Research Programs

Dedicated research programs across a diversity of regions (e.g. high, mid and low latitude sites) must be developed and adequately funded to detect species movements and likely interspecies interactions, in order to predict, and possibly prevent, the impact of invasion resulting from global climate change. These goals will best be accomplished via focused, mechanistic studies of invasive species to inform and predict how global climate change factors may impact native species, invasive species and interact with local stressors to affect invasion success.

Increased Coordination

Build partnerships among federal agencies and academic institutions to enhance capacity for detecting, responding to, and managing invasive species.

Develop Rapid Response Plans

Risk assessments are needed to prioritize species that deserve rapid responses. Strategies need to be developed for rapid response to these species. Further, an emergency fund for such efforts should also be established.

Vector Management

These scenarios of the "ghost of Christmas future" support the need to strikingly enhance vector management policies to prevent future invasions.

Expand Educational and Outreach Programs

It is imperative for the public to understand the implications of their actions, with or without the climate change message. Increased efforts should be initiated to translate the combined risks from climate change and biological invasion to the public through real-world examples.

National Strategy for Monitoring

Global climate change will result in the loss of species; yet without adequate monitoring the extent of this loss may not be known. For example, some species are endemic to Alaska; however, as a result of the large size and remoteness of the state, many species still are unknown. Extensive monitoring across environments is needed to document the distribution of native species, identify range shifts, and detect invasions.

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Validation of PCR-Based Assays and Laboratory Accreditation for Environmental Detection of Aquatic Invasive Species

Approved by ISAC on May 25, 2012

"Validation is the bridge between research and regulatory decisions!"
(Anything else is jumping across the abyss of unknowns to any possible conclusion!)

This white paper provides:

a) Background information on the use, accuracy and reliability of PCR-based assays such as environmentally sampled DNA (eDNA) for early detection of aquatic invasive species (AIS) and;
b) Recommendations for establishing a system for validating assays and accrediting laboratories that report on the presence or absence of AIS.

This white paper was developed by the members of ISAC and discusses the need for developing validation requirements for Polymerase Chain Reaction (PCR) and other DNA-based molecular assays that are increasingly being used to detect AIS. It does not provide a simplified checklist for evaluation of their ability to detect AIS. Rather, it is intended to demonstrate the need for a required and regulated framework to validate these molecular assays. A regulated framework for validation would greatly increase confidence in the utility of DNA-based assays and better enable decision-makers and managers regarding AIS detection, prevention, monitoring and control.

ISSUES

Aquatic invasive species can have major environmental, economic, and in some cases human health impacts. The National Invasive Species Council's (NISC) bureaus and agencies have a responsibility to make the most appropriate decisions possible and take timely action. However, traditional visual methods for the early detection and identification of invasive species are difficult and time-consuming to conduct in aquatic systems and maybe inadequate to support effective and timely actions. Delays, data gaps, and inaccurate information can be costly and allow an invasive species to become too well established and widespread to apply effective rapid response and eradication plans.

Molecular assays based on PCR can amplify tiny amounts of DNA in water samples (i.e., environmental DNA or eDNA) and detect the presence of AIS at high levels of sensitivity and specificity (Blanchet 2012, Darling and Mahon 2011, Jerde et al. 2011). This approach is currently being used to detect Asian carp species and zebra and quagga mussel larvae in water systems. There is increasing interest in the development of additional PCR-based assays for these and other AIS.

These factors, coupled with the increasing availability of rapid molecular assay systems (kits) are greatly expanding the use of PCR-based technologies to detect AIS. Due to their relative sensitivity, the use of molecular assays is causing major paradigm shifts in the way that AIS are detected, monitored, and controlled.

The successful application of molecular technologies will increase the speed and number of samples that can be analyzed, making early AIS detection more likely and increasing the probability that AIS populations will be contained and eradicated. However, there are numerous concerns regarding the reliability of these assays which were originally developed for research applications rather than to inform regulatory and/or management decisions (e.g., Longshaw et. al. 2012). They have been conducted without appropriate validation of methodology or definition of minimum laboratory requirements. These concerns are especially important when molecular tests are the only means available/possible to detect AIS because "traditional" methods cannot be used. However, the consequences of trusting an assay that has not been validated could be far more damaging, destructive, and long-lasting in loss of agency credibility or harm to non-target species than the damage caused by the arrival and establishment of an invasive species. Due to their potential negative regulatory, economic, and ecological impacts, one may question why managers or agencies would attempt to make decisions regarding AIS based on results from assays that have not been validated and/or conducted by unaccredited laboratories.

Regardless of what assays are used, making authoritative public announcements and appropriate regulatory decisions requires a suitable number (statistically valid) of certifiable samples to be collected under strict protocols.

The establishment of well regulated sample collection, sample custody, and analyses protocols will allow NISC agencies and their partners to provide authoritative public announcements and make appropriate regulatory decisions in order to avoid wasteful use of regulatory resources, unnecessary public confusion or unrest, national and international commercial damage, and legal remediation.

To ensure that decision makers can make appropriately informed decisions and most effectively use these powerful new techniques, they need to be assured that the information generated by assay results is reliable via high analytical specificity and diagnostic specificity for the target species in a tested water body. However, decision-makers often have little information concerning the accuracy or reliability of the various DNA detection methods being used or the performance quality of the various laboratories conducting them. In addition, commercial assay kits used by some laboratories are protected from public release of specific data concerning their contents and internal protocols that are considered confidential commercial business information. While a method may meet the needs for research applications and be published in a peer-reviewed journal, this does not equate to an assay being judged or accepted as validated for other applications. Decision-makers may initiate rapid response efforts based solely on eDNA evidence with little assurance of its quality or limitations. Currently, there is no formal process for approving sampling and testing protocols. Ultimately, this reduces the effectiveness of efforts to combat the introduction and spread of AIS.

Although there is increasing use of PCR assays to detect AIS in aquatic systems and increasing reliance on them for making critical regulatory and management decisions, there is no formal organizational process for approving sampling and testing protocols and questions concerning their effectiveness remain.

Each of the AIS-detection assay/sampling protocol systems that are developed requires validation. They must be evaluated to ensure that the protocols used yield results that are: specific to the target organism (specific), can detect low concentrations of eDNA (sensitive), consistent over time (reproducible); provide results that are within acceptable limits of variation from replicate samples obtained from both within and among locations (precise); able to yield similar results under differing environmental and sample conditions (robust), and consistent with positive and negative control samples (accurate).

A new assay needs to be evaluated against an established "gold-standard" or compared diligently to a long accepted methodology; validated for their specificity, sensitivity, precision, accuracy, robustness, and reproducibility; and, laboratories conducting the assays need to be accredited.

Moving from traditional visual identification methods to molecular detection assays involves complex paradigm shifts which have great importance for decision-makers. It is a shift from the identification of organisms at a specific location and time to the detection of the current and/or past presence of an organism. It is also a paradigm shift from direct detection (i.e., collecting a specimen) to indirect detection (i.e., collecting DNA shed from an organism).

These paradigm shifts have enormous import for managers and require a correlation between "traditional" and "newer" approaches. Decision makers must have a clear understanding of the strengths and weakness of all the methods used.

The terms "validation" and "accreditation" have been defined by several quality assurance organizations and have been standardized domestically and internationally in support of trade and other agreements. However, these definitions have not been uniformly applied to the discussion of PCR-based assays for AIS detection in environmental samples ("validation" in this white paper is defined as "the systemic and scientific evaluation of an assay to accurately define its usefulness, robustness, accuracy, specificity, sensitivity, and repeatability."). A lack of clear and consistent terminology has led to confusion and can hinder the progress of AIS detection or control efforts.

The clear and consistent use of standard terminology is critical to avoiding confusion and understanding and effectively communicating the information used to make decisions.

No assay is 100% accurate and consistent. The utility of PCR-based AIS early detection methodologies for decision-makers would be greatly increased if decision-makers and the public had clear measures of the specificity, sensitivity, precision, and accuracy of reported results. Increased confidence in eDNA detection would allow regulators to make more informed decisions and take scientifically based actions at the earliest possible stage of invasion when rapid response and eradication efforts have the highest likelihood of success. It would also greatly augment public communication efforts. Similarly, independent performance testing, and eventually laboratory accreditation could direct decision-makers to high performing laboratories that consistently generate trustworthy results that can be tracked over time and among locations.

The eventual outcome of evaluating laboratory performance would be the establishment of a national reference laboratory fully capable of meeting international requirements and standards.

Application of the concepts of assay validation and laboratory accreditation are urgently needed. For example, a lack of certainty and confusion regarding DNA-based detections has led some agencies to require, separate and independent verification of initial assay results before taking action (Darling and Mahon 2011). The degree of confidence that regulatory officials and private and public stakeholders have in the specificity, accuracy, and robustness of current eDNA assays for correctly informing AIS decisions could be greatly increased by establishing systems for performance testing, validation and accreditation to benchmark both methodological and laboratory performance.

Asian carp species currently threaten the Great Lakes. The use of eDNA evidence indicating that Asian carp could be in Lake Michigan has been the subject of heated controversy (Jerde et al., 2011) and extensive review (see below). Currently, litigation is shackling Asian carp control because of a lack of convincing correlations between visual traditional methods (i.e., having captured fish at a specific location and time) versus PCR detection of carp DNA in water samples. In early 2010, the Solicitor General informed the U.S. Supreme Court, in part, that the use of a PCR eDNA assay for detecting invasive Asian Carp as:

> "the best information available . . . the government has not rejected any option . . . compelled by the facts . . . Nothing in federal law warrants second-guessing its expert judgment that the best information available today does not yet justify the dramatic steps Michigan demands."[1]

Again, in February 2010 testimony to the US House of Representatives stated:

> "Because eDNA is a new approach to assessing the presence of Asian carp and is being applied operationally before standard independent scientific review could occur, the Corps (U.S. Army Corps of Engineers) continues to collaborate with the University of Notre Dame to determine what eDNA does and does not tell us and continues to research how to improve the usefulness of this technology to inform management decisions."[2]

More recently in May 2011, a U.S. Army Corps of Engineers expert gave testimony in the U.S. Appeals Court stating:

> "Efforts to corroborate eDNA results with traditional methods of capturing fish have not been successful thus far."[3]

Perhaps the most compelling testimony that eDNA is an emerging technology and not validated is from the U.S. Army Corps of Engineers before the U.S. Supreme Court dated January 2010:

> "Scientific research typically follows a process that includes a hypothesis regarding a topic, predictions about experimental or observational results based on the hypothesis, gathering of data, analysis of data, assessments of prediction accuracy, revision of the hypothesis, conclusions, and iterations if necessary. This process allows for revision and fine-tuning of hypotheses as predictions are tested and more information becomes available, and allows for an increasingly better understanding about the phenomenon or topic of interest. Hypotheses regarding the robustness and information content associated with positive eDNA detections are currently being formulated by Notre Dame. . . . In scientific research processes and terminology, this would involve further gathering and analysis of data to be used in testing predictions and assessing hypotheses regarding the inferential power of the eDNA method. This is a critical process in making sure that strong scientific conclusions are made and appropriate management actions undertaken." [4]

Could the "best information available" be devastatingly wrong if there is a deficiency of solid science (still in research mode) or a lack of validation of the assay or accreditation of the laboratory before it is applied in a real life situation? Indeed, because of the regulatory, interstate commerce, and legal concerns regarding use of eDNA to detect the presence of Asian carp, the methodology and laboratory which developed it have undergone an extensive independent review process (Battelle Memorial Institute 2010, United States Environmental Protection Agency 2010, Asian Carp Regional Coordinating Committee 2012). The laboratory audit reviewed and reported on: 1) staff qualifications, training and quality assurance roles, 2) laboratory facilities, 3) field sampling practices, 4) eDNA methodology, 5) PCR methodology, and 6) quality assurance systems (United States Environmental Protection Agency 2010). This audit may be an initial step for future eDNA assay validation and laboratory accreditation.

At the very least, laboratories using eDNA technology for early detection and monitoring of AIS should be offered the opportunity for independent performance testing as has been done for dreissenid mussel PCR detection (Frischer et al. 2011) with public access to performance results so that entities seeking the laboratories' services can be confident of their accuracy, reliability, and capacity to detect target species' DNA. The availability of such independent performance testing could be a step in the eventual development of comprehensive eDNA methodology validation and laboratory accreditation systems.

RECOMMENDATIONS

To encourage the development of a validation/accreditation system for AIS eDNA detection methodologies and laboratories, ISAC recommends that the NISC member Departments and Agencies and their partners consider adoption of the following recommendations.

- Encourage and develop funding for the National Academy of Sciences to undertake a review of the reliability and effectiveness of PCR and other DNA-based applications for detecting AIS, focusing on establishment of appropriate validation processes and a framework and standards for this new and potentially invaluable tool in the early detection, eradication, prevention and control of AIS.
- Establish and fund an ongoing independent performance testing program for laboratories utilizing DNA-based AIS detection methodologies such as that recently undertaken for evaluating laboratory performance in PCR detection of dreissenid mussel larvae (Frischer et al. 2011). Testing

1 U.S. Memorandum in Opposition, January 2010, to the US Supreme Court hearing Michigan's renewed petition for closure of the Chicago Area Waterway System to prevent Asian Carp species from entering the Lake Michigan from the Illinois River system.

2 Statement of: Major General John Peabody, Commander, Great Lakes and Ohio River Division, U.S. Army Corps of Engineers, Before: Subcommittee on Water Resources and Environment Committee on Transportation and Infrastructure, United States House of Representatives on Asian Carp and the Great Lakes, February 9 2010

3 Slater. U.S. Army Corps of Engineers, US Court of Appeals, 7 Circuit, May 5, 2011.

4 Declaration of Dr. Elizabeth C. Fleming, Senior Executive Service, Director of the Environmental Laboratory, and Civil Works Business Area Lead at U.S. Army Engineer Research and Development Center. App. 30a http://www.supremecourt.gov/specmastrpt/us_appendix_to_renewed_opp.pdf

- results should be made public so that managers may make informed decisions about the accuracy and reliability of a laboratory's performance when including an eDNA component in an AIS monitoring and early detection system.
- Utilize lessons learned in establishing a laboratory performance testing system to fully develop a validation/accreditation program(s) for other invasive species eDNA methodologies and laboratories.

BACKGROUND

Molecular PCR-based assays amplify trace amounts of DNA by orders of magnitude. Using short highly specific segments of DNA called primers; these primers are a critical component of the assays that can detect the presence of target organisms' DNA in water samples. This approach has been used in attempting to monitor the spread of quagga mussels (*Dreissena rostriformis bugensis*) by detecting DNA from their larvae in plankton net tow samples in the western United States (Hosler 2011, Turner et al. 2011) and the free DNA of Asian carp (i.e., environmental DNA or eDNA) in water samples from the Chicago Area Waterway System (Jerde et al. 2010, 2011). A large proportion of DNA is "conserved" among species. Only a small amount is unique to a species. Isolating specific and stable primers to bind to "i.e., probe" a target DNA sequence is difficult. Primer selection and PCR protocols can profoundly alter the results obtained. Primers must be highly specific to the target species (Darling and Mahon 2011).

The need to rapidly detect AIS has led to the recent development of numerous PCR-based and other molecular detection assays for the analysis of environmental samples (Darling and Blum 2007, Li et al. 2011, Darling and Mann 2011, Mahon et al. 2011, Blanchet 2012). Numerous molecular assays have been published for detection of aquatic organisms including microbial pathogens (i.e., viruses, bacteria, protozoa and helminthes) (Toze 1999); bivalves (Claxton and Boulding 1998); fish (Jerde et al. 2011); and amphibians (frogs and salamanders) (Goldberg et al. 2011). However, the various molecular assays that have been used to detect a target organism's DNA in water samples obtained from the field (United States Environmental Protection Agency 2010) have not been standardized using validated assays conducted in accredited laboratories. Only one report of a laboratory performance evaluation that examined 11 laboratories' performance in identifying zebra mussel larva (veligers) DNA is available (Frischer et al. 2011). This "double-blind, round robin" evaluation using standardized low target organism density water samples found that PCR techniques *were the least reliable detection method.* The traditional visual microscopic examination under polarized light was most reliable and accurate (75.8% versus 96.3% accuracy in determining presence/absence). This finding has led to legitimate concerns regarding the accuracy and reliability of eDNA for early AIS detection.

Of 11 laboratories tested, the most common error was failure to detect eDNA (i.e., false negative test result) in samples known to contain veliger DNA. There was also considerable variation (lack of precision) among laboratories. The average precision of more "experienced laboratories" as defined by the study was 86.9% while that for laboratories with less experience with these assays was considerably lower at 62.4% (Frischer et al. 2011). This round-robin conclusion will not be totally known until the information on the diagnostic sensitivity and specificity become known with assay validation.

As with all assays, a major concern is positive test results that do not reflect the true presence of the AIS at a location (i.e., false positives). This may be due to sample contamination, problems with the assay, DNA from dead target organisms, and/or only the target DNA and not the organism itself being present. DNA may last 14–25 days in the water column (Dejean et al. 2011) and can be carried by water currents far from the actual range of the target species. For example, it is not clear if Asian carp DNA in areas of the Chicago Area Waterway System was a "false positive" finding (Jerde et al. 2011). In addition, carp DNA could have been released into waterways from rinse water from fish markets and/or from ice melt-water used to store harvested carp (Asian Carp Regional Coordinating Committee 2012). There are several possible sources of target species DNA, such as 1) sewage discharge, 2) discarding remains of target species in slaughter and processing activities, 3) dead individuals captured elsewhere and transported by humans or wildlife and, 4) uptake of water from a target species habitat by boats or barges followed by discharge into an area outside the target species' range (Darling and Mahon 2011, Asian Carp Regional Coordinating Committee 2012).

Conversely, false interpretations may occur due to insufficient test sensitivity or because, even if target species is present, AIS DNA may not be in the water sample collected or the concentration is below the limits of detection of the assay (Darling and Mahon 2011).

Four potential sources of error in eDNA testing are:

1. lack of assay sensitivity and/or specificity,
2. insufficient laboratory quality assurance, i.e., sample contamination, failure to follow protocols, and misinterpretation of results,
3. ineffective sampling design and protocols to maximize potential for discovering the target species DNA, and
4. lack of understanding of the relationship between a detection of a target species' DNA and actual target species presence, including DNA persistence and opportunities/vectors for its transport outside the range of the target species (Darling and Mahon 2011, Asian Carp Regional Coordinating Committee 2012).

Existing Validation Requirements for DNA-based Detection Assays

Currently, at least two federal agencies have some level of regulatory control regarding PCR assays developed and validated for marketing in the United States. The Federal Drug Administration (FDA) is responsible for enforcement of the Federal Food, Drug, and Cosmetic Act that covers *in vitro* diagnostic devices which are a subset of medical devices "intended for use in the diagnosis of disease and other conditions, including determination of the state of health, to cure, mitigate, treat, or prevent disease or its sequel." The Animal and Plant Health Inspection Service through the Center for Veterinary Biologics regulates the licensing and sale of diagnostic kits used in detecting animal diseases under the authority of the Virus Serum Toxin Act. Both agencies are involved in assuring that commercially available kits for running assays are safe, effective, reliable, and truthful in their label claims.

Existing Accreditation of Laboratories Offering DNA-based Detection Systems

Currently, there is no required independent or regulatory oversight of laboratories conducting and performing DNA-based AIS assays when using in-house primers, reagents, protocols, and technologies. There are numerous "quality" concerned organizations which orient their policies and philosophies towards globally standardized laboratory quality and analytical assay validation. These "quality" associations/organizations are voluntary. Membership brings recognition of a laboratory's effort to conform to quality standards in several areas important to reliable and reproducible laboratory operations and outcomes.

Generally "inspections" (i.e. audits, reviews, verifications, etc.) by quality organizations are conducted by a team of experts from member laboratories. Each team member can be specialized in some area of concern to the quality standards being verified. Typically areas reviewed, observed and audited are facilities, equipment, personnel qualifications, protocols, references, mechanisms of internal control and direction, etc.

There are areas of exceptional standards in some regulatory programs for the prevention, control, and eradication of animal disease where participation may need to meet mandatory standards for facilities, equipment, and personnel. Many protocols in these regulated laboratories are standardized in accordance with international trade agreements or other legally binding documents. Personnel must follow the various "Uniform Methods and Rules" used when testing for animal pathogens of commercial and economic significance. It appears that human and animal health is well on its way to utilizing reliable, validated assays for information regarding disease. There is also a system in place for plant health certification by way of testing for plant pathogens. These programs could serve as models for development of validation of protocols and accreditation of laboratories providing DNA-based AIS detection systems.

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Invasive Species and E-Commerce

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ISSUE

Internet commerce (hereafter e-commerce[1]) is a growing and vital part of the U.S. economy. Total e-commerce sales in the U.S. for 2011 totaled $194 billion, an increase of 16% over 2010. From 2002 to 2011, the proportion of reported e-commerce sales in the U.S. grew from about 1.4% to 5.5% of total retail sales (U.S. Census Bureau News 2012). Globally, e-commerce is expected to increase at a rate of 13.5% annually, amounting to $1.4 trillion in yearly sales by 2015 (Enright 2011). A portion of this activity includes the sale and trade of living organisms. Unfortunately, such organisms and other organisms that they may carry can be invasive species, defined by U.S. Executive Order 13112 as "alien [non-native] species whose introduction does or is likely to cause economic or environmental harm or harm to human health." Order 13112 mandates that Federal agencies work to ensure that they do not promote e-commerce in invasive species, because the order states that these agencies should "not authorize, fund, or carry out actions that are likely to cause or promote the introduction or spread of invasive species…."

A number of government entities have jurisdiction over aspects of e-commerce. The U.S. Department of Agriculture, Animal and Plant Health Inspection Service (USDA, APHIS) has jurisdiction over plants, livestock, and their products. The Department of Interior (DOI), U.S. Fish and Wildlife Service (USFWS) has jurisdiction over wildlife. Shipping services are overseen by the Department of Homeland Security (DHS), U.S. Postal Service (USPS) with jurisdiction over imports and interstate trade (Federal government) and intrastate trade (state governments). However, e-commerce as a sector is evolving and expanding in volume at a rate that may exceed these various capacities to address the associated risks of introduction and spread of invasive species.

ACTION

This briefing paper, adopted by the U.S. Invasive Species Advisory Committee (ISAC), provides:

- Background information on the linkages between invasive species and e-commerce, and
- Recommendations to strengthen action by the Federal government to address the invasive species risks posed by e-commerce.

BACKGROUND

Scientific analyses and informal reviews of commercial websites and specific niche markets in the U.S. reveal a wide range of invasive species for sale, including many species regulated by state and federal laws. Identifying and managing the risks associated with e-commerce is particularly challenging because the Internet simply serves as a mechanism for processing commercial and non-commercial transactions between groups and individuals. Unlike other vectors of introduction of invasive species, e-commerce is not a physical means of moving organisms.

An analysis of the full role of the Internet in the spread of invasive species needs to consider the ranges and amounts of:

- Sectors and species traded. For example, pet and aquarium species, horticultural and agricultural species (plants, cuttings, seeds, soils), live food and bait, scientific and educational supplies, firewood and other biofuel stocks, and herbal or medicinal products;[2]
- Internet tools for the sale or trade of organisms or products

1 E-commerce refers to "the buying and selling of products or services over electronic systems such as the Internet and other computer networks… [and] also includes the entire online process of developing, marketing, selling, delivering, servicing and paying for products and services." While typically associated with the World Wide Web, e-commerce can also incorporate technologies such as e-mail, mobile devices, and telephones. (Wikipedia, s.v. "E-commerce," accessed December 30, 2011, https://en.wikipedia.org/wiki/E-commerce.)

2 This list will likely keep growing with the use of new species, end-uses, and pathways.

that may be pathways for other organisms. These might include commercial websites, auction sites such as eBay, classified ad websites such as Craigslist, online forums such as those hosted by Google Groups, Yahoo Groups, Facebook, Google+, and specialist groups, and other online social networking and communication tools;
- Actors in supply chains. Actors include importers, domestic breeders, resale entities, box stores and large-scale retailers, small businesses, brick and mortar stores, e-tailers, interest groups such as 4H Clubs, collectors and specialist groups interested in particular species, and the general public; and
- Shipping agents and routes. Shippers can include public entities such as the U.S. Postal Service and private companies such as FedEx and DHL. Routes of regulatory significance include imports into the U.S. and interstate and intrastate trade.

The scale and diversity of e-commerce present regulatory difficulties. Individuals and companies that sell through e-commerce may not be legally registered businesses and frequently do not disclose their specific location of operation. They frequently fail to acquire the appropriate licenses and permits, or to use appropriate labeling for packages. Sellers that are out of state or out of the country may undermine local efforts with cooperative retailers to limit the sale of invasive species. Sellers can use the relatively high level of anonymity associated with the Internet to skirt accountability and avoid identification, regulation, and prosecution. Shipping agents may not necessarily know they are transporting potentially harmful organisms, or that they are transporting live organisms at all.

A range of scholarly work has addressed various aspects and sectors of e-commerce and other forms of trade in invasive or potentially invasive species. For instance, the Global Invasive Species Program (GISP 2009) provides a broad overview of the issues, Peters et al. (2006) examine the horticultural trade in Minnesota, Kay and Hoyle (2001) cover aquatic weeds sold through the Internet and mail, and Stam et al. (2006) and Walters et al. (2006) focus on the sale of species of *Caulerpa* in Florida. A number of reports have tried to quantify the volume of species being imported into the U.S., including Romagosa (2011) and Defenders of Wildlife (2007) for wildlife, and Smith et al. (2008) for fish. Recent studies from other countries include a broad overview of the issues in New Zealand (Derraik and Phillips 2010), an examination of the Internet pet trade in the U.K. (Parrott and Roy 2009), an analysis of the role of e-commerce in the spread of introduced freshwater aquarium fish in Brazil (Barroso de Magalhães and Jacobi 2010), and reports by the International Fund for Animal Welfare (IFAW 2005, 2008) on trade in endangered species and their parts through the Internet.

We focus on those invasive and potentially invasive species that are formally regulated by Federal or state governments and thus restricted from trade and transport, such as those listed as noxious weeds or injurious wildlife. Regulation of these species can include prohibiting or otherwise restricting import into the U.S., forbidding movement between states, and prohibiting intrastate trade and other actions controlled by states. In some cases, a species can be regulated, not because it is itself invasive, but because it can carry pests, pathogens, or parasites directly, in packaging, or during conveyance. We divide our analysis into four areas:

1. Issues specific to e-commerce such as composition of the e-retail industry, Internet-related regulations, and online vendor and consumer awareness;
2. Relevant issues more broadly associated with commerce such as international and interstate regulations on trade, postal and courier services, species identification, and hitchhikers;
3. Control mechanisms such as web surveillance, outreach and education; and
4. Recommendations to NISC member agencies.

Live Animal Imports into the U.S.

From 1999–2009, over 2.8 billion live animals were legally imported into the U.S., the vast majority of which (about 88%) were ornamental fish (Romagosa 2011). Despite the fact that scientific and common names are required and submitted on Form 3-177 or attachments to the form (see Appendix 1), one study found that the USFWS Law Enforcement Management Information System (LEMIS) recorded the full taxonomic data for only 3.8% of all shipments (i.e., those species listed under the Convention on International Trade in Endangered Species) (Smith et al. 2008). Most species also entered without extensive scrutiny of their potential to harm the environment, agriculture, or human health in the U.S. Surveys of aquatic species sold in the Great Lakes region through the Internet and other sources found a significant percentage of known invasive species available for sale, misidentification of species, and high levels of live invertebrates hitchhiking on plants (Keller and Lodge 2007).

A significant portion of this volume in traded organisms can be associated with e-commerce. Experts estimate that there are at least 4,000 businesses and 15,000 individuals advertising reptiles over the Internet. Numbers of e-commercial traders of horticultural species are difficult to estimate, but conservative guesses place them in the tens of thousands (ISAC 2011).

ISSUES SPECIFIC TO E-COMMERCE

The Internet has unquestionably revolutionized how individuals and businesses communicate and make transactions, removing former geographical barriers and obstacles to communication. With regard to the movement and trade of invasive species, three areas are particularly notable: 1) increased diversity of commerce, 2) decreased ability of governmental authorities to implement and enforce regulations, and 3) the increasing role of the Internet in public awareness and education.

Kudzu (Pueraria montana *var.* lobata)

Pueraria montana (Lour.) Merr. var. *lobata* (Willd.) Maesen & S. Almeida, introduced to North America from Asia and commonly known as kudzu, is a high-profile, invasive vine. In the southeastern U.S., kudzu is very widespread and forms famously dense blankets over whole trees. Despite this, multiple listings (e.g., "20 Seeds Pueraria lobata Kudzu Seeds") on eBay offer seeds for sale, and search engines readily find online businesses selling seed, such as B & T World Seeds.

Suppliers are motivated in part by Internet sites that host questions such as:

> "Where can I buy Kudzu plants/seeds? Hi Everyone, I would like to buy Kudzu plants/seeds, but everywhere I look, I only see Kudzu destroying products for sale. No plants. I am quite aware of the rapid growth and the capabilities of this invasive species, so please don't tell me why not to buy it. I need it for observation purposes in a closed environment. Thanks, Batman" (Yahoo Answers 2012)

Specialty cultivars of kudzu can also be found online:

> "*Pueraria lobata* 'Sherman's Revenge' (Sherman's Revenge Variegated Kudzu) For the gardener who has everything or as the perfect gag gift for a garden party, yes, it's variegated kudzu. Originally discovered in Japan, it was named by plantsman Barry Yinger, who's never met a variegated plant he didn't like. This fast-growing deciduous vine…rumors of several feet per hour when established are probably true…is covered with lovely trifoliate light green leaves edged in white. The vines are adorned with small clusters of Nu-grape soda smelling flowers in late summer. If you're going to have a weed, it might as well be variegated. Not recommended for states where it has been banned, and because there are so many, we won't ship out of state." (Plant Delights Nursery 2012)

Increased Diversity

The Internet has vastly expanded the range of people and businesses engaged in the movement and sale of plants and animals. For example, while a combination of large and small "brick and mortar" stores once held sway in the pet and aquarium trade, individual hobbyists, collectors, breeders, wholesalers and others can now easily engage in the sale of species. Some set up Internet-based businesses that cut out middlemen, maintain a low-cost infrastructure, access a broad range of potential buyers, process sales over the Internet, and use postal or express delivery services to send purchased merchandise. Traditional retailers have likewise diversified by adding Internet and mail sales to their businesses. This model has expanded the geographic reach of the market, facilitating transactions across the country and around the world.

The array of mechanisms for making transactions is also highly diverse, including standard retail websites, auction sites, local business and want ads, portals that facilitate communication between buyers and sellers, and specialty chat forums and user groups. Social media such as Facebook, Twitter, and Foursquare are further changing the landscape, particularly through informal retail arrangements. A shift to person-to-person transactions will likely continue, raising significant questions about whether and how e-commerce can be regulated.

Regulations and Enforcement

The Internet has facilitated an increase in sales of organisms by individuals, not just by lowering overhead and transaction costs, but also by helping sellers circumvent state and federal regulatory requirements. For example, brick and mortar stores are frequently required by states or countries to apply and pay for licenses that allow them to move and sell species, and for permits to breed or import species into the country. Individuals sellers are often unaware of these requirements or may deliberately circumvent them by being located in another jurisdiction. Such sellers are often hard to trace, it may be difficult to hold them accountable, and efforts by enforcement agencies to pursue them may be time-consuming and expensive. The Internet has also made it easier to exchange information on how to avoid regulations, such as by falsifying documents or using trans-shipments, transfers between more than one shipper.

Those who want to be responsible may find it hard to find out what the relevant regulations are. There is no one comprehensive listing or guide to federal and state regulations on the transport and sale of plants, animals, and materials that could be a pathway for the transport of invasive species. Many states lack a standard means for communicating with non-registered businesses that work over the Internet. Policy-makers are still debating whether only in-state sellers should be licensed, how to design the process for licensing, and how to enforce regulations, all difficult issues. Many would argue that current policies have not kept up with the age of the Internet, resulting in an increasingly unregulated sector of trade in invasive and potentially invasive species. The current situation thus favors largely unregulated, virtual sellers, puts conventional stores at a significant competitive disadvantage, and increases the risks of the introduction and spread of invasive species.

Education and Public Awareness

Perhaps the greatest commercial virtue of the Internet is that it allows individuals to readily find information, albeit sometimes unreliable, about products and sales. Individuals can locate sellers, details of the features and care of species, and information about how to circumvent rules or smuggle banned species. The Internet can also be a powerful tool for educating consumers. A number of targeted efforts in stores and at trade shows, such as Habitattitude™ and Be PlantWise, have helped educate those involved in conventional, face-to-

Illegal Importation of Freshwater Ornamental Fish

Based on a search of websites, including news articles published on Practical Fishkeeping, there appear to be a number of ways to illegally import prohibited, freshwater, ornamental fish.

One avenue of illegal importation seems to center on websites such as Aquabid.com, where buyers bid on fish offered by a wide variety of sellers worldwide. As on eBay, fish are sold and shipped to the highest bidder. Some sellers on this website offered fish that were illegal to import into the U.K. and indicated that they would send them to buyers in the U.K. via ground postal service without the import license, health documentation, or notification of the Fish Health Inspectorate required by U.K. law. In some cases, fish were sent without documentation via EMS Express Mail, a service for documents and merchandise run by postal operators of the Universal Postal Union. Another apparent route for illegal importation of ornamental fish was for the seller to ship fish to a trans-shipper in a nearby country where the fish were not banned; buyers in the country where the fish were illegal then arranged with the trans-shipper to have the fish delivered to them.

A third means of illegal importation was to falsely declare the contents of a shipment on a custom declaration in the hope of getting the shipment past customs and wildlife inspectors. This may also involve shipping ornamental fish that are prohibited in one country first to a nearby country that does not prohibit them. They are then smuggled into the prohibiting country via ground transport to avoid the more rigorous inspection of international air shipments of live animals.

It is likely that these routes are being used to illegally import prohibited species into the U.S.

face transactions. Such efforts are increasing their presence on the web, and there is a need to develop more effective methods to harness the power of the Internet to inform those involved in online transactions.

ISSUES MORE BROADLY RELATED TO COMMERCE

While the Internet is facilitating a surge in the sale and trade of organisms, it cannot actually serve as a means for the physical movement of species. E-commerce is thus related to a number of other broader areas, including international and interstate commerce, postal and delivery services, taxonomy and species identification, and hitchhikers.

International and Interstate Commerce

Official federal and state lists of invasive species apply equally to electronic and non-electronic commerce. At the federal level, provisions of the Lacey Act on injurious wildlife allow USFWS to regulate the importation and interstate transport of animal species including wild mammals, wild birds, amphibians, reptiles, fishes, crustaceans, and mollusks that may prove harmful to humans, agriculture, horticulture, forestry, wildlife, or resources for wildlife in the U.S. Importers of wildlife are required to submit USFWS Form 3-177 (Appendix 1: Live Wildlife Import Declarations—Form 3-177). Similarly, the Plant Protection Act of 2000 (PPA) provides for the listing of noxious weeds, broadly defined as any plant or plant product harmful to crops, livestock, poultry, conditions for agriculture, irrigation, navigation, natural resources, public health, or the environment. Under this act, APHIS also regulates the importation and interstate movement of plant pests such as insects and pathogens and the commodities that may carry them. These regulations are named for the sections of the Code of Federal Regulations (CFR) in which they appear. For example, "Q37" applies to plants for planting and "Q56" applies to fruits and vegetables. Both the PPA and the Lacey Act work in tandem with the commerce clause of the U.S. Constitution to allow the federal government to regulate trade of potentially harmful species into the U.S. and across state borders.

State governments can similarly regulate the transport, sale, and possession of invasive species within states and many have developed legislation and regulations similar to the Lacey Act and Plant Protection Act that list prohibited species.

Such regulations are also becoming more frequent at the levels of the county and municipality, creating an increasingly complex regulatory system. As noted above, there is no single, regularly updated resource that includes all of this regulatory information and requirements to assist sellers trying to abide by regulations.

Postal and Express Delivery Services

Since the Internet is often used for transactions across significant distances, purchased specimens are generally sent by mail or express delivery services such as those of USPS, DHL, FedEx, and UPS. Such services have their own set of regulations concerning the shipment of species. All packages sent from abroad require a manifest that lists their contents and may be subject to non-intrusive inspection, such as with dogs or X-rays. Manifests for express delivery consignments must be submitted electronically, which allows for advanced targeting through a range of risk screening measures. DHS Customs and Border Protection (CBP) thus has some idea of what to expect prior to delivery of a package sent by express consignment. In contrast, packages send by international mail are currently exempt from the requirement for electronic manifests, which prevents advanced targeting and requires inspection on the spot. Such inspections may or may not occur depending on volume of mail, timing, port of entry, and availability of personnel. Customs experts have noted cases where multiple shipments of a particularly questionable species were sent under the assumption that at least one would make it through customs and quarantine inspections. Intentional mislabeling of contents can further increase the difficulty in halting the entry of packages containing invasive species.

Shipments of organisms may alternatively travel as cargo, as in the case of some bulk shipments and species relatively tolerant of long times in transit or harsh travel conditions.

Governmental Roles and Responsibilities in E-Commerce of Invasive Species

AGENCY	AUTHORITY	COVERAGE
USDA/APHIS	Plant Protection Act of 2000: 7 CFR 360 Noxious Weed Regulations	Federally listed noxious weeds
USDA/APHIS	Plant Protection Act of 2000: 7 CFR 319.37 (Q37) Plants for Planting 7 CFR 319.56 (Q56) Fruit and Vegetables	Imported plants, fruits and vegetables that may be invasive or serve as hosts for other invasive pests
USDA/APHIS	Animal Health Protection Act of 2002: 9 CFR 122 Organisms and Vectors 9 CFR 121 Select Agents and Toxins	Animals and animal products that may carry livestock diseases, and permits for moving various pathogens and their vectors
DOI/FWS	Lacey Act: 18 USC § 42-43 Importation of Injurious Species (50 CFR 16), 16 USC § 3371 3378 Prohibited Acts related to Unlawful Taking of Fish or Wildlife (50 CFR 10-15)	Federally listed injurious wildlife and prohibitions against the import, export, transport, sale, purchase, receipt, or acquisition of fish or wildlife in violation of U.S., state, or foreign law
DHS/CBP	Homeland Security Act of 2002: 6 USC § 201-239 Directorate of Border and Transportation Security (7 CFR 319 & 330; 9CFR 94-96)	Border quarantine and inspection stations
DHS/CBP	Homeland Security Act of 2002: 6 USC § 201-239 Directorate of Border and Transportation Security (7 CFR 319 & 330; 9 CFR 94-96)	Express delivery services
USPS	Postal Reorganization Act of 1970: 39 CFR 20 International Mail and 39 CFR 111, 121, and 122 Domestic Mail	Postal services
Federal Government	U.S. Constitution	Imports and interstate trade
State Governments	U.S. Constitution	Intrastate trade

Shipments are then subject to inspections by CBP and the USFWS. Cargo currently has a significantly lower rate of examination for live organisms than do express consignments or mail. The reasoning appears to be largely that live organisms are more likely to be express shipped than to be transported as cargo in order to keep them viable.

Taxonomy and Species Identification

Proper naming and identification of species is a major issue in both traditional commerce and e-commerce in live organisms, as for example in the trade in aquarium plants (Thum et al. 2011). One problem is that new or little-known species are often particularly sought after. Other challenges include that:

- the exact species may not be known to science;
- the organism may not be identified in the shipment to the level of the species, but rather just to the genus, family, or other, higher level;
- species may be incorrectly identified, intentionally or unintentionally;
- a trade or common name may be used that does not refer unambiguously and consistently to any one species;
- taxonomic classifications and scientific names can change over time; standards for naming and labeling species for shipment and sale do not exist.

Lack of correct taxonomic information obviously makes it very difficult to regulate the import and sale of species, and to assess the volume and risk of trade in a species.

Hitchhikers

In some cases, the major risk may not be from the species being moved, but from "hitchhikers," other species that are moved along with it. Trade in species is a major vector for the introduction and spread of pests, pathogens, parasites, and diseases. Insects and fungal pathogens may be transported on nursery stock, cuttings, growing media, and other associated material. Diseases of humans, livestock, and wildlife health can be carried by introduced fish, insects, and other animals. Packaging, such as soil, water, or seaweed used to pack bait or crustaceans, may include potentially invasive species such as weeds, algae or snails. Solid wood packaging used to transport a variety of goods may be contaminated with insect pests or fungal pathogens. Movement of firewood can present similar risks.

REDUCING THE RISK OF INTRODUCTIONS FROM E-COMMERCE

Despite the breadth and scope of sales of invasive species through e-commerce, there are some positive steps and tools that can be used to mitigate the risks associated with Internet trade in invasive species. Two main types of approaches are through 1) accountability and enforcement, and 2) outreach and education.

Accountability and Enforcement

Managerial tools and methods that focus on accountability target the responsibilities of the buyer, the seller, and the intermediaries. Webcrawlers have been used with varying degrees of success to monitor the Internet for the sale of illegal plant materials on a range of commercial sites from eBay and Amazon to Google Groups and Etsy. Enforcement authorities can use Internet tools to identify sellers and to employ a range of responses to address first time and repeat offenders. However, enforcement may need to rely on local personnel to track down sellers and buyers or subpoenas and court orders to obtain electronic transaction data, and those determined to sell harmful species can use aliases, naming practices, and other means to avoid detection. In the case of international vendors, there are few avenues for enforcement at present. Even so, the data collected through these efforts may help analyze trends and assessment of risks, and help those charged with enforcement to better target possible pathways.

Other tools focused on accountability may seek to educate the buyer, for example with online warning labels or pop-ups when an invasive species is about to be purchased. This method is often employed by online retailers and catalog sellers, particularly in the nursery industry, and is useful in cases where certain states ban specific species. Requiring electronic manifests with international mail would allow advance targeting of potentially risky packages. Such efforts could be complemented by increased cooperation among DHS, USPS and FWS on border control activities designed to prevent introductions through international mail, express consignments, and cargo shipments. Protocols for consistent identification and labeling could help identify incoming risks and track trade. More generally, adapting existing regulations for postal and express services regarding injurious wildlife and noxious plants to the realities of the age of the Internet and e-commerce would help bring enforcement efforts into the 21st century. There is some concern that better enforcement may drive trade in invasive species underground where it would be even more difficult to track, but little evidence exists for or against this.

Outreach and Education

Various mechanisms could be used to increase the awareness of buyers and sellers and their access to information on how to avoid violating regulations or introducing invasive species. A web-based clearinghouse with a constantly updated catalog of federally and state-listed species could be established. Development of resources for scientists to name and for traders to identify species would be useful. Campaigns such as Habitattitude™ that present the problems caused by invasive species could help educate the public. By including general information on the risks and care of species, such campaigns might further benefit trade by educating sellers and buyers about how to maintain or improve the health of purchased species.

Other non-regulatory approaches might include changes in the policies of online retailers and commercial forums, informing Internet service providers about the legalities of trade in organisms and their role in respecting them, and developing codes of conduct and best management practices for individual sectors and interest groups. Because codes of conduct or local campaigns designed to discourage use of invasive species could put brick and mortar stores at an economic disadvantage compared to Internet retailers, such campaigns need to work to also influence non-local sales or develop appropriate incentives for local vendors.

RECOMMENDATIONS TO NISC MEMBER AGENCIES

We conclude that relevant federal agencies need to adjust existing regulations and enforcement practices to better mitigate the risks of trade and transport of invasive species through e-commerce. We offer the following recommendations to enhance our collective ability to engage in e-commerce without promoting the introduction or spread of invasive and potentially invasive species.

1. U.S. Fish and Wildlife Service (DOI) and Animal and Plant Health Inspection Service (USDA): Expedite listing processes for the national importation of injurious wildlife and other animals and noxious plants under the Lacey Act, the Plant Protection Act and the Animal Health Protection Act to better assess and address emerging invasive species threats, including those associated with e-commerce.
2. U.S. Fish and Wildlife Service (DOI): Incorporate all species-specific data submitted with Form 3- 177 declarations for wildlife imports into the Law Enforcement Management Information System (LEMIS) or another accessible database.
3. Department of Homeland Security: Expand cooperation with the U.S. Postal Service to monitor and increase the capability to interdict international mail containing potentially invasive species and encourage the U.S. Postal Service to expedite requirements for advance electronic manifests associated with packages sent through international mail similar to current practice for international express mail and consignments.
4. Animal and Plant Health Inspection Service (USDA): Expand the scope of webcrawlers and related enforcement and monitoring activities used by the Smuggling Interdiction and Trade Compliance unit to include a broader

array of invasive plants and plant pests, and enhance cooperation with

5. U.S. Fish and Wildlife Service (DOI) to address injurious wildlife.
6. Agricultural Research Service (USDA): Support development of and capacity for an Internet clearinghouse of federal and state-listed invasive species such as injurious wildlife, other animals and noxious weeds and of relevant regulations. Such a resource could be located at the National Agricultural Library's Invasive Species Information Center or another appropriate website and should include relevant agency contact information and a general reporting form that allows the public to report suspected violations.
7. U.S. Fish and Wildlife Service (DOI), Animal and Plant Health Inspection Service (USDA), National Oceanic and Atmospheric Administration (Department of Commerce [DOC]) and other relevant agencies: Provide a reference catalog or database of taxonomic resources that commercial interests can use to verify the taxonomic identity of organisms in trade.
8. Department of State and Office of the U.S. Trade Representative: Given that a significant portion of e-commerce entities is based outside the U.S., explore further cooperative and legal measures with foreign trading partners and relevant international institutions and other bodies to address the illegal import of invasive species into the U.S.
9. U.S. Fish and Wildlife Service (DOI), Animal and Plant Health Inspection Service (USDA), National Oceanic and Atmospheric Administration (DOC): Promote outreach to individuals and businesses involved in the sale and exchange of species over the Internet to reduce intentional and unintentional sales or purchases of species listed as invasive in the U.S. or particular states.

APPENDIX 1: *Live Wildlife Import Declarations*[3]

As a general rule, all live wildlife[4] imported into the United States[5] for any purpose must be imported through a "designated port."[6] Under certain limited circumstances, arrangements may be made to use a port other than a designated port. In any event, such shipments must be declared on import and inspected by FWS or a designated alternative, such as CBP.

With limited exceptions, all live wildlife imports must be declared on a FWS Declaration Form, Form 3-177, as a pre-condition to inspection and clearance before any imported live animals may be released to an importer. Form 3-177 calls for submission of detailed information on the contents of the shipment. The importer must provide, among other information:

- Purpose code (i.e., personal, zoo, commercial, educational, circus, pet)
- Scientific and common names of each species in the shipment
- Quantity of specimens by species in the shipment
- Country of origin
- Transportation code (i.e., mail, air cargo, personal accompanying baggage)
- CITES Permit number, if applicable
- Wildlife source code (i.e., wild, captive bred, ranched)
- Total value in U.S. dollars
- Indication if venomous
- FWS License number if applicable

There are limited exceptions when such declarations are not required. For example, imports of live shellfish and fishery products imported for human or animal consumption, or fish taken for recreational purposes in Canada or México do not require the filing of Form 3-177. However, exceptions are not available if a permit is required under Part 16 (Injurious Wildlife), Part 17 (Endangered species), Part 18 (Marine mammals), Part 21 (Migratory birds), Part 22 (Eagle permits) or Part 23 (CITES). If the shipment is considered a "commercial" shipment[7] of live animals, the importer or exporter may have to obtain an import or export license under 50 CFR Part 14.91.

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3 The regulations contain a variety of exceptions or conditions that apply to wildlife products (dead, preserved, dried, etc.), museum specimens, personal baggage, and household effects, etc.

4 "Wildlife" includes "any wild animal, whether alive or dead, including without limitation any wild mammal, bird, reptile, amphibian, fish, mollusk, crustacean, arthropod, coelenterate, or other invertebrate, whether or not bred, hatched, or born in captivity, and including any part, product, egg, or offspring thereof." (50 CFR Section 10.12) Domesticated animals (50 CFR Part 14.4) are exempt unless specimens are from a wild population.

5 Import means any wildlife introduced or brought into or landed on any place under the jurisdiction of the U.S. For imports, see 50 CFR Parts 14.61–14.62; for exports see 50 CFR Parts 14.63–14.64.

6 There are 18 designated ports, listed in 50 CFR Part 14.12. If special permits are not required, as under ESA or CITES, imports may also be cleared at certain border ports with Canada and México or special ports in Alaska, Puerto Rico, the Virgin Islands, and Guam, provided completed Form 3-177 Declarations are submitted.

7 "Commercial" means offering for sale or resale, purchase, take barter or transfer for gain or profit. There is a presumption that eight or more specimens constitute commercial use and a declaration is required.

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ISAC

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Harvest Incentives: A Tool for Managing Aquatic Invasive Species

Approved by ISAC on May 15, 2014

PREFACE

Invasive species are estimated to cause the United States tens of billions of dollars in environmental and economic damage each year (Pimentel et al. 2005). Prevention, containment, and control of invasive species are necessary to protect native species and ecosystems, economic development in agriculture and industry, and animal and human health. Recently, there has been significant interest in managing invasive species populations by encouraging their harvest.

This briefing paper, adopted by the Invasive Species Advisory Committee (ISAC), a Federal Advisory Committee to the National Invasive Species Council (NISC), provides a framework for approaching harvest incentive programs for aquatic invasive species. The objectives of the paper are to:

- Discuss the biological, ecological, and socioeconomic considerations involved in programs that utilize harvest incentives to manage aquatic invasive species.
- Provide recommendations for consideration in the development, implementation, or support of incentive or harvest efforts that target aquatic invasive species.

For the purposes of this paper, the terms 'aquatic invasive species' and 'aquatic nuisance species' are considered equivalent; the later term is defined by the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 [PL 106-580 § 1003(1):]:

"Aquatic nuisance species (ANS) are nonindigenous species that threaten the diversity or abundance of native species, the ecological stability of infested waters, and/or any commercial, agricultural, aquacultural, or recreational activities dependent on such waters."

BACKGROUND

Harvest incentive programs are generally defined as strategies that promote utilization of an organism for various purposes, including food, clothing, and biofuel. Recently, such strategies have been used to complement species or habitat management plans. Examples of programs that encourage harvest of invasive species with an associated incentive include:

- *Bounty Payments*—A program in which a predetermined amount of money is paid to an individual upon satisfactory evidence of collection of a specified organism.
- *Subsidy Payments*—A program in which production costs are reduced to improve success in bringing a product to market.
- *Contractor Payments*—A program that provides direct payment to a service provider to remove or harvest an invasive species.
- *Commercial Harvest*—An effort that is undertaken, usually

Nutria Harvest: Two Approaches

Nutria have significantly invaded both Chesapeake Bay and Louisiana where different harvest strategies are being utilized. Chesapeake Bay officials decided to pursue eradication because the population size (±100,000) was small enough to allow for eradication given available resources.

Rather than encourage public harvest, the program began with a "knock-down" phase where high density populations could be found and traps, firearms, and dogs could be easily employed (Nutria Management Team 2012). As the population density decreased, the program put relatively more effort into deploying improved detection methods before they could use the standard removal techniques. Because bounties are illegal in Maryland, the program relies on wildlife specialists from the U.S. Department of Agriculture for continued harvest. In contrast, millions of nutria are thought to exist in Louisiana. As the Louisiana Department of Wildlife and Fisheries noted, "Currently in Louisiana, there is no known method that will completely eradicate nutria, nor is it a viable option." Instead of pursuing eradication, Louisiana's Coastwide Nutria Control Program consists of an economic incentive payment of $5 per nutria tail delivered by registered participants to collection centers. The goal of the Program is to encourage the harvest of 400,000 nutria annually from coastal Louisiana (Hogue and Mouton 2012).

privately, when a perceived market exists for an invasive species that can be harvested for sale in the free market.

- *Recreational Harvest*—Programs that allow recreational fishing, hunting, or trapping of invasive species by modifying seasons, license requirements, bag limits or other regulations.
- *Community Harvest*—Efforts by general public volunteers, lake stewards, interns, students, etc. to restore aquatic ecosystem quality and health

Before implementing a harvest incentive program there must be a clear vision of the goal or outcome desired, a robust plan to achieve the goal, outreach that addresses stakeholders, program monitoring, and follow-up actions. It is critical to recognize that program goals will vary based on biological, ecological, and socioeconomic considerations. The specific objectives within harvest incentive programs will also vary and may include population control, engagement of the public, or increased awareness of impacts.

Incentivizing or encouraging harvest may not be the most effective method of control or may need to be employed in tandem with other efforts. Multiple strategies that employ adaptive management may be the most effective in achieving the identified goal for the target species. Consequently, careful analysis should be conducted to select methods that are cost-effective and both socially and legally acceptable. Once an incentive program is selected for implementation, outreach should communicate the impacts of the target species on the environment, economy and public health and why harvest is necessary. Finally, the development of an exit strategy is critical to help determine program termination or adaptation within the program. Identifying and utilizing measurements of program success will be a key component of the exit strategy.

Harvest incentive programs have demonstrated success in reaching program objectives of managing some (e.g., Bomford and O'Brien 1995, Choquenot et al. 1998, Dedah et al. 2010) but not all (e.g., Hassall and Associates 1998, Bartel and Brunson 2003, Barbour et al. 2011) non-native or other undesirable species. These latter studies have reported such programs as ineffective at reaching the intended management objective, damaging, costly, and producing a poor return on investment compared to other available control measures. Until a thorough analysis is conducted, incentive programs that aim to manage aquatic invasive species should only be undertaken following careful consideration of the biological, ecological, and socioeconomic specifics of the targeted species. Furthermore, these programs should only be implemented if there is a strong commitment to accomplish measureable goals and objectives and effective methods have been identified that will ensure removal or long-term sustained reduction of the target species. Harvest incentives alone are generally not an option for eradication of aquatic invasive species as they typically cannot meet the generally accepted criteria for a successful eradication campaign (Bomford and O'Brien 1995).

A Multifaceted Approach to Species Management

Adoption of a harvest program is under review by the Asian Carp Regional Coordinating Committee. In a recent study, Garvey et al. (2012) identified a number of key issues if market approaches are to be utilized effectively including re-colonization potential during harvest, nutritional composition of fish, and how an incentives program might function.

The study noted that developing a diverse Asian carp market could be effective as a control activity. For example, efforts focusing solely on large fish may not deliver population control. Therefore all sizes of carp must be harvested and markets for multiple fish sizes must be developed to allow effective population control.

The study highlights the need to invest in baseline research to develop an effective strategy, as simply encouraging the public to "go forth and use" will almost certainly not achieve desired goals. However, combined with an understanding of the target species biology, harvest incentives may play an important role alongside other control measures.

Biological Considerations

Invasive species exhibit distinct life history traits that enable them to thrive in new habitats and traditional species management principles may not be directly applicable to invasive species management. Consequently, understanding the population dynamics and life cycle of the species is the foundation for the successful management of invasive species (Barbour et al. 2011). Therefore, prior to implementing an incentive program, the population dynamics of the targeted species (e.g., density dependent processes, demographic structure) should be examined. However, limited biological information should not hinder management actions upon the target species. In circumstances where the target species may spread rapidly, undertaking control efforts despite limited understanding of the success of the outcome should proceed (Simberloff 2003).

Monitoring the population of the target organism is essential to determine the effectiveness of the program; ideally the target organism must be detectable at low densities and found relatively easily. If the target organism is cryptic, located in an isolated area, or inhospitable environment that cannot be easily accessed, the effort required to both monitor the population and the effort needed to remove individuals will be high. Consequently, monitoring will be an important component throughout the life of the program.

Ecological Considerations

The management of aquatic invasive species through harvest may cause potential damage to non-target species (e.g., bycatch, increased human activity, habitat or ecosystem damage). Given the complex interactions among species and their environment, it is often difficult to predict the outcome of the removal of invasive species. Therefore prior to initiating any harvest program, a careful evaluation of the functional roles of invasive species within the ecosystem and trophic interactions with native species is encouraged.

Biological invasion can result in the loss of biodiversity as well as an alteration of ecosystem processes. Therefore, the simple removal of the target species will likely require additional effort to restore the native community. For this reason, habitat restoration and long-term monitoring will be crucial components of the management effort.

Human Health Considerations

Incentive programs can involve members of the public who may be untrained in the acceptable methods of capturing and handling the target species. If information and training ae not provided there may be serious consequences. For example, lionfish (*Pterois* spp.) tournaments have risen in popularity and serve as a means to raise awareness and manage localized populations of this invasive species (Morris 2012). However, improper handling of the fish can lead to significant injury if the venomous spines puncture skin and consumption may result in contraction of the seafood-toxin illness ciguatera. Even when harvested by professionals, there are concerns for encouraging the harvest of invasive species, as public health risks may result from handling, utilization, or consumption of the species. Before promoting harvest, the target species should be carefully evaluated for potential risks to human health.

Socioeconomic Considerations

Managers shouldconsider various socioeconomic factors in choosing and designing an effective management strategy. Managers must weigh the social and political consequences of implementing, or not implementing, harvest incentives against the potential benefits and risks to the resource. The public's involvement in an incentive program will be motivated by a variety of biocentric and anthropocentric values (Jones et al. 2012), which will likely vary widely among individuals. Conflicts may arise from differing perceptions between resource managers who must consider all aspects of such programs and advocates for harvest incentives who may be more focused on the perceived benefits.

MARKET ECONOMICS AND UNINTENDED OUTCOMES

Using harvest incentives successfully will depend in part on the value of the harvested commodity, the cost associated with the harvest, and the minimum profit acceptable to the harvester. The marginal cost and effort needed to capture the target species is expected to increase as the population decreases. Thus, managers need to plan accordingly by either raising bounties (if used) or employing additional control mechanisms. In some cases the use of supplementary control and ecosystem restoration methods may enhance the effectiveness of the program; in others the concurrent use of control methods may reduce the economic viability of harvest programs. Careful planning can help anticipate and mitigate these issues.

Perhaps the biggest challenge to using incentivized harvest is its potential to generate unintended outcomes (i.e., perverse incentives) that could unintentionally cause the further spread or persistence of the target species. For example, people may come to rely on the income that harvest of the target species generates or may develop a preference for the species and value its long-term presence. These perverse incentives may encourage the intentional release of species back into the control area or into previously non-invaded areas, in order to promote the success of the introduced species (Lambertucci and Speziale 2011). Such activities have been observed as part of traditional restoration activities, where people have "seeded" favorite nonnative gamefish into areas that had been restored for native fishes. Additionally, individuals that perceive incentivized harvest as a benefit in one region may intentionally introduce the species into new regions. Anticipating the potential for possible unintended outcomes will be an essential exercise prior to implementing an incentive program.

LEGAL ISSUES

In choosing an effective management strategy, managers also need to consider existing federal, state, and local laws. Managing aquatic invasive species with the use of harvest incentives is complex when multiple jurisdictions are involved. Federal and state agencies often have differing policies or restrict certain harvest activities. For example, the 2013 Python Challenge, sponsored by the Florida Fish and Wildlife Conservation Commission and Everglades National Park, permitted hunting in Big Cypress National Preserve and state lands; however, hunting was prohibited in adjacent Everglades National Park. In order to ensure the greatest reduction in the number of target species in a population, it may be necessary to use alternative control methods or introduce legislation to allow access to all lands.

Market demands may require a species to be supplied in a particular way, yet these requirements may not always comply with federal regulations. For example, certain markets may prefer live Asian carp, but their listing as injurious wildlife under Title 18 of the Lacey Act (18 U.S.C. 42) prohibits live interstate and cross-border movement. Specific legal constructs may not be able to accommodate market demands particularly when measures have been taken to minimize further introduction. Therefore, amending legislative and regulatory authorities may be required to create effective harvest incentive programs.

OUTREACH

Regardless of which mechanism is selected for control, strong public outreach is essential. When the public understands and accepts the need for control of a specific species then a successful incentivized harvest program can be realized (Hassall and Associates 1998, Dedah et al. 2010). Building support for an incentive program and encouraging active participation requires outreach that communicates the impacts of the target species on the environment, economy, and public health. Outreach programs may also generate financial support for the effort from decision-makers and support from communities that may have disparate moral, ethical, emotional, or cultural views on killing the target species.

Stakeholder engagement can also help resolve possible differences prior to program implementation. For example, what is considered a pest by one person may be an essential income source to another and a source of recreational pleasure to a third. Outreach and facilitated discussions with the public can help resolve disputes before program implementation begins.

There may be situations when incentivized harvest is used to raise awareness of aquatic invasive species issues rather than providing for a level of species control. In these cases, the harvest activity becomes the vehicle through which a message is communicated. For example, the *2013 Python Challenge* provided financial incentives for the harvest of non-native constrictor snakes in southern Florida. Although this effort resulted in few individuals removed from the population, the attendant media coverage provided significant outreach benefits by increasing awareness of invasive species and steps that public can take to mitigate impacts and prevent future invasions

CONCLUSION

The success of any harvest incentive program to address aquatic invasive species will depend upon numerous biological, socioeconomic, and legal considerations. Programs that encourage harvest may be a successful management tool in targeting small, distinct populations; in high priority areas within a larger invasion; or they may play a supplementary role within larger control programs. Their use, however, will require careful review, planning, and monitoring to ensure success and that they do not unintentionally lead to further spread of invasive species, cause additional harm to native species, or waste valuable resources.

RECOMMENDATIONS

Incentivized harvest is just one type of strategy used to manage and control invasive species. As dedicated funding for invasive species management is limited, resource managers should conduct a basic analysis of various options based on the life history of the target species and relevant socioeconomic factors to identify the most effective solution. The anticipated costs and risks of eradication should be weighed against long-term control and management that mitigates damage to an acceptable level. ISAC recommends the following be considered before implementing any harvest incentive program:

1. *Develop a management plan prior to undertaking a harvest incentive program. The plan should incorporate each of the following:*
   a. Program goals and measures of success: The goal of the program and the method used to measure progress toward completion of the goal should be clearly identified.
   b. Cost analysis: Once the decision has been made to reduce numbers of a specific invasive species, then costs (both monetary and welfare) of various potential control methods should be compared to identify the most cost-effective method.
   c. Target species' biology: Managers should gather the best available information about the species.
   d. Address humane treatment: Processes for humane treatment of target species, including euthanasia, should be established.
   e. Human and wildlife health risks: Before managers encourage harvest, they should ensure that the target species and the associated harvest activities do not pose a significant risk to human or wildlife health through any aspect of the harvest program.
   f. Potential ecological outcomes: Species interactions and the effect of removing or reducing the target species from the ecosystem should be evaluated prior to program start.
   g. Risk of creating perverse incentives: Before initializing a program, identify the possible perverse incentives that may exist and include a plan to address them.

2. *Incorporate the following into the implementation of any harvest incentive program after the development of a management plan:*
   a. Monitor for unintended consequences: Incentive programs and commercialized harvest of invasive species may create perverse incentives that do little to encourage long-term control or eradication. The program should be adequately supervised to prevent such occurrences.
   b. Monitor for ecological disturbances: Project activities should be evaluated to reduce any potential disturbances to native populations or habitats.
   c. Incorporate adaptive management: Harvest may be successful early on when there are large, easily accessible populations, but other control measures may be needed as species density declines or if methods are unsuccessful.
   d. Encourage active enforcement to help mitigate perverse incentives by creating a disincentive to release the target species back into the control area or previously non-invaded areas.

3. *Incorporate Outreach*
   a. All outreach should be clear about the goals of the program to encourage public and stakeholder support throughout the development, implementation and completion the program.
   b. All outreach should help ensure that public does not grow to "desire" the targeted species. Success is more likely if the public understands the long-term harm the species can cause.
   c. When outreach is the primary objective of a harvest program be sure to carefully plan for maximum media exposure.

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Background Paper on Systematics

Prepared by the ISAC Committee on Research, May 22, 2015

Systematics is the science that identifies and groups organisms by understanding their origins, relationships, and distributions. It is fundamental to understanding life on earth, crops, wildlife, and diseases, and provides the scientific foundation to recognize and manage invasive species. Invasive species are a growing threat to biosecurity; human and animal health; agricultural security and trade; environmental security; and economic health.

The Federal Interagency Coordinating Committee for Invasive Terrestrial Animals and Pathogens (ITAP) Systematics Subcommittee prepared the Situation Report, "Protecting America's Economy, Environment, Health, and Security against Invasive Species Requires a Strong Federal Program in Systematic Biology" (2008). The purpose was to create awareness of the crisis in systematics in Federal agencies and to advocate the need for a permanent, viable, and coordinated Federal Systematics Program.

The Situation Report demonstrates how systematics is a vital cornerstone for work on biodiversity and invasive species. It describes the crisis in systematics:

- Lack of systematists;
- Lack of training at universities and post graduate training/mentoring;
- Lack of permanent, life-long job opportunities in systematics;
- Biological collections are incomplete and/or in poor condition; they languish in substandard facilities, lacking adequate staffing, technology, and coordination.
- Lack of appropriate facilities for collections (e.g., buildings with climate control, fire prevention, information technology hardware/software, research labs, plans for continuation of operations in case of a natural or terrorist catastrophic event).
- Lack of a comprehensive national/global exchange of bioinformatics.

Where is the crisis in systematics happening? It is evident in many places: in the United States Federal government; at universities, zoological parks, and botanical gardens; as well as in similar institutions in other countries.

The Situation Report includes a recommendation for a comprehensive survey of the federal systematics capacity and needs. The survey will inform a 10 year Action Plan by the federal government to enhance the systematics capabilities of federal agencies with the vision *"To strengthen national and global systematics to enable prediction, effective prevention, and management of invasive species to ensure biosecurity; public health; economic, environmental, and agricultural security; and sustainability"*. The Plan will delineate actions and budget estimates for consideration by Agency and Congressional decision makers. It will catalyze strengthening of systematics resources for Federal agencies to predict, prevent, and manage invasive species.

The Invasive Species Advisory Committee (ISAC) makes recommendations to the Federal government agencies that have an invasive species portfolio. This systematics recommendation strives to motivate action in the agencies that have been identified in the Situation Report as the agencies with systematics capabilities in the Federal government.

The USDA Agricultural Research Service (ARS) and the Smithsonian Institution are repositories of a large amount of the systematics collections and human capabilities for systematics essential work on invasive species. Conducting the Survey of their systematics capabilities and needs is urgent. The Survey will describe actions in research, specimen-based collections, a biodiversity informatics network, and educating future systematists.

Systematics expertise and use is distributed across the federal agencies so participation needs to be inclusive and coordinated, particularly in the areas of research, specimen-based collections, informatics networks, and the education of future systematists. The Situation Report recommends that a Systematics Interagency Coordinating Group incorporating relevant federal agencies monitor implementation of the Plans; document successes and failures; and provide information to the White House, Office of Management and Budget, and federal agencies to facilitate decision-making on systematics programs.

ISAC recommends that:

1. The USDA Agricultural Research Service (ARS) and the Smithsonian Institution conduct a survey and gap an-

alysis of their Federal systematics collections, associated resources, and capabilities.

2. Survey results should be translated into an ARS 10 Year Systematics Action Plan and a Smithsonian Institution 10 Year Systematics Action Plan.
3. The Plans should be used by agency leaders to improve the systematics capabilities and resources of the agencies in all taxa to strengthen their ability to predict, prevent and manage invasive species.
4. The coordination of federal systematics efforts referenced in the Federal Interagency Committee for Invasive Terrestrial Animals and Pathogens (ITAP) *Situation Report* should be implemented.[1]
5. The ITAP's Systematics Subcommittee should assist the agencies in the Surveys recommended by the Situation Report.

1 Federal Interagency Committee on Invasive Terrestrial Animals and Pathogens (ITAP) Systematics Subcommittee. 2008. Protecting America's Economy, Environment, Health, and Security against Invasive Species Requires a Strong Federal Program in Systematic Biology.

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Enhancing the Effectiveness of Biological Control Programs of Invasive Species by Utilizing an Integrated Pest Management Approach

Approved by ISAC on October 30, 2015

PREFACE

Invasive species threaten agriculture and natural ecosystems. Methods for control and management have evolved over time, and often rely on combinations of techniques and long-term planning. This white paper discusses the benefits and increased potential for long-term success of invasive species biological control programs when utilizing an Integrated Pest Management (IPM) approach.

Integrated control was first defined by Stern et al. (1959) as applied insect pest control, which combines and integrates biological control and chemical control to maintain a pest population below an economic injury level. Integrated control has evolved over time to include all taxa, as well as prevention, other control, and ecological, health, and economic aspects. IPM emphasizes long-term prevention of damage through the utilization of various techniques such as chemical control, biological control, physical control, habitat manipulation, modification of cultural practices, and resistant varieties using combinations that are compatible and produce the desired outcome. An IPM approach can be implemented in agricultural, residential, and natural areas.[1]

Biological control is an integral component of IPM programs and has far greater potential for success when used in an IPM system. Land managers rely on information provided by researchers during the time period leading up to the release of the biological control agent (generally an insect or pathogen), to help guide them on the best procedures, approaches and use of the agent. As the number of biological control programs increase, information from successful and unsuccessful programs can be used to increase the chances for the successful establishment of biological control agents in the future. Post-release monitoring can inform land managers on how to achieve their management goals by guiding them in the most effective use of adaptive Best Management Practices (BMP). Post-release information is also critical for assessing the economic costs and benefits of an IPM approach. Implementing such efforts may increase the success of biological control efforts and the confidence of private and public land managers when making decisions about integrated invasive species management programs.

This white paper will discuss:

- benefits for biological control efforts through inclusion in an IPM approach;
- partnership programs to facilitate the incorporation of biological control in IPM programs of invasive species;
- incorporation of long-term stewardship in biological control programs;
- model program for integrated biological control of an invasive species;
- ecological approaches to maximize success of biological control;
- genetic advances in biological control.

BENEFITS OF BIOLOGICAL CONTROL EFFORTS THROUGH INCLUSION IN AN IPM APPROACH

Biological control agents are intended to reduce an invasive species population through a typical predator-prey or pathogen-host response. The incorporation of other control methods, such as chemical, mechanical, and cultural, may also help to maintain a balanced population of both predator and prey or pathogen and host. This balance minimizes the chance of dramatic swings in invasive species populations, and therefore, failure of the program. At the beginning of a biological control program, when an invasive species population is large, the number of agents that can be released to achieve a noticeable population decline may not be possible. In such cases, the use of other control methods may reduce the invasive species population to a level that is more responsive to the success of the biological control agent. An example is the use of chemical and biological control on diffuse knapweed, *Centaurea diffusa*. Wilson et al. (2004) showed that a low

1 University of California Statewide IPM Program, http://www2.ipm.ucanr.edu/WhatIsIPM

rate of the herbicide picloram or clopyralid applied to diffuse knapweed in early summer increased the percentage of plants infested by the root-boring beetle, *Sphenoptera jugoslavica*, and improved diffuse knapweed control compared with using the weevil alone.

In addition to combining multiple control methods, IPM approaches require a thorough understanding of the interactions between invasive species and beneficial species, as well as the dynamics of these organisms under varying environmental conditions and factors, all within an economic framework for assessment of costs and benefits. For example, Pacific Northwestern orchard systems have several key diseases and arthropod pests that detrimentally affect their production (Jones et al. 2009). Control of these pest species involves the integration of selective pesticides and numerous species of key natural enemies. In such complex systems, frequent monitoring is needed to assess the population levels and seasonal phenology of target pests and natural enemy species and to identify periods of high vulnerability to disruption of natural enemies in orchards. This information is used to better understand the relative ecological benefits of different IPM programs. A web-based decision aid system (DAS) in Washington State was developed for pest management of apple, cherry, pear, peach and nectarine orchards (Jones et al. 2009). The website has ten insect models and three disease models and integrates weather data, model predictions, and pesticide recommendations (including known natural enemy and non-target pest effects) to provide management recommendations. This IPM system has been widely adopted by growers and pest control advisors in many orchards in the Pacific Northwest.

PARTNERSHIP PROGRAMS TO FACILITATE THE INCORPORATION OF BIOLOGICAL CONTROL IN IPM

To further enhance the potential effectiveness of biological control programs, federal land management agencies that oversee and conduct control operations utilizing biological control agents would greatly benefit by partnering with federal, state, and local scientists and agencies. These should include partnerships and collaborations from a variety of relevant pest management disciplines (Carruthers 2011). Such partnerships should develop strategies to monitor, evaluate/measure and communicate meaningful project results. This would facilitate more effective IPM and adaptive management approaches. In particular, increased emphasis on post-release monitoring data could be instrumental in the decision-making process to enhance the success and economic performance of biological control programs. To accomplish this, project funding must be established that takes into consideration the full duration of the project, as well as the broader framework of the IPM approach. While specific funding for post-release monitoring has been requested from many agencies over the past several years, such support has not been viewed as a funding priority.

As an example of the increased effectiveness of biological control through collaboration, the success of tropical soda apple, *Solanum viarum*, control with the beetle, *Gratiana boliviana,* in Florida (Diaz et al. 2012) was the direct result of the cooperative effort of many individuals and organizations including U. S. Department of Agriculture-Agriculture Research Service (USDA-ARS), Animal and Plant Health Inspection Service (APHIS) and Natural Resources Conservation Service (formerly U. S. Soil Conservation Service), University of Florida Cooperative Extension, Florida Department of Agriculture and Consumer Service, South and Southwest Florida Water Management Districts, and the St. Johns River Water Management District. APHIS supported the rearing, distribution and release of the biological control agents, followed by the involvement of many other agencies in the monitoring, implementation, and adaptive management efforts. In addition, private landowners, primarily ranchers, also greatly assisted with the program by allowing access to their property for the collection and redistribution of beetles. The success of these partnerships led to the biological control program receiving the Florida Entomological Society's Achievement Award for Research Teams in 2010.

Another example of a successful partnership is the rearing, release and establishment of the parasitoids of the emerald ash borer, *Agrilus planipennis*. In this case, a Michigan lab developed the production technique that provided natural in-field emergence of adult parasitoids, particularly the larval parasitoid, *Tetrastichus planipennisi,* and the egg parasitoid, *Oobius agrili*. The lab produced over 500,000 parasites that were distributed in 17 states. USDA APHIS and ARS, working together, developed life table analyses for evaluation of the impact of the biocontrol agents, including establishment rates, spread and parasitism levels. Adults were released into each of six forest sites where their population numbers increased rapidly. Recent information indicates that 21.2% of emerald ash borers were parasitized by the fall of 2015. In addition, APHIS, again partnering with ARS, provided data and submitted a petition for release of another parasitoid species.

INCORPORATION OF LONG-TERM STEWARDSHIP IN BIOLOGICAL CONTROL PROGRAMS

Federal agencies should include long-term stewardship and the sustainability of desired ecosystem functions as the ultimate goal of any biological control program. To this end, part of a successful integrated pest management program may include rehabilitation of the ecosystem to a healthier condition. Such a functional state may not be possible with biological control alone. Rehabilitation practices should be developed to facilitate resilience to the ecosystem and help prevent re-invasion or replacement of one invasive species with another. This will require coordination among many federal agencies and partners, including those responsible for developing the biological control programs and those in charge of managing the resources.

For example, tamarisk or saltcedar, *Tamarix* spp. biological control in some riparian areas with the northern tamarisk beetle, *Diorhabda carinulata*, is being used in combination with chemical and mechanical control methods. The IPM approach has a holistic goal of increasing the ecosystem health through restoration of native riparian vegetation to mitigate excessive water loss and reinvasion, while also providing important nesting habitat for the threatened southwestern willow flycatchers, *Empidonax traillii extimus* (Dudley and Bean 2012).

MODEL PROGRAM FOR INTEGRATED BIOLOGICAL CONTROL OF AN INVASIVE SPECIES

TEAM Leafy Spurge (The Ecological Area-Wide Management of Leafy Spurge)[2] is an example of how biological control can be successful when incorporated into a broad regional approach that includes integrated strategies, as well as strong partnerships, outreach and education components, and a stewardship program.[3] By the mid-1990s, leafy spurge, *Euphorbia esula*, caused over $130 million in losses each year in the northern states. TEAM Leafy Spurge was established in 1997 as a six-year IPM research and demonstration project to effectively manage leafy spurge. TEAM Leafy Spurge was funded and led by the USDA-ARS in partnership with APHIS, Bureau of Land Management, Forest Service, National Park Service, Bureau of Indian Affairs, Bureau of Reclamation, U.S. Geological Survey, USDA Cooperative Extension Services, land grant universities, state agencies, county weed managers, and landowners. The IPM approach combined different management tools, including a mix of multi-species grazing programs, herbicides, reseeding, tillage, burning and/or clipping, in combination with insect biological controls to more effectively, affordably, and sustainably manage leafy spurge over a large area. The combined integrated approach with multiple tools not only maximized the overall control of the invasive populations, but also provided more flexibility for land managers and more site-specific options. The results of the program additionally refined the BMP protocol for insect release location, timing, number, appropriate species per site and optimal spurge densities and site habitat types for natural enemy release. The partnership also included a stewardship program by tracking successes and failures, costs and benefits, and subsequently analyzing the results to improve the efficacy and success of the biological control agents.

By 2011, the five-year research and demonstration program helped reduce the total size of the leafy spurge infestation by 75% of its projected range without intervention. Controlling the invasive weed also led to the recovery of some endangered species, such as the western prairie fringed orchid, *Platanthera praeclara*. Multiple agencies working together to provide research and extension coordination met the goal of implementing a long-lasting invasive weed control program.

2 http://www.team.ars.usda.gov/index2.html
3 http://www.team.ars.usda.gov/v2/publications/brochures/brochures.html

ECOLOGICAL APPROACH TO ACHIEVE MAXIMUM SUCCESS IN BIOLOGICAL CONTROL

Because the historical success rate of classical biological control programs is quite variable with 12 to 83% of the projects resulting in establishment of the biological control agent and suppression of the invasive species (Clarke and Walter 1995, McFadyen 1998), increased emphasis should be placed on supporting research funding for cost-benefit analysis of biological control programs to assist prioritization. To reduce the risk of failure, a more ecological approach is also needed to achieve maximum successful selection of effective natural enemies, as well as to better understand the biology of the target pest and biological control species, and ecology associated with regional establishment. While there are multiple factors that can influence the effectiveness of biological control agents, increased attention should be paid to: 1) characterizing natural enemy candidates and target host using morphological taxonomy or genetic markers at the onset of a program, 2) utilizing climatic matching models to accurately determine the most likely areas of successful establishment of candidate agents, 3) understanding biological control agent host-finding behavior and attack rates, and 4) elucidating the most relevant habitat characteristics of biological control agents in their place of origin to better predict rates of colonization and spread in the invaded range (Hoelmer and Kirk 2005, Nowierski et al. 2002).

As an example of the latter factor, Nowierski et al. (2002) examined the habitat associations of four species of *Euphorbia* and seven species of their associated flea beetle species, *Aphthona* spp. Their goal was to identify important habitat factors that might be conducive to flea beetle establishment and impact on leafy spurge in North America. Through ordination models of both *Euphorbia* and *Aphthona* species in their native range in Europe, they identified the preferred soil, nutrient, and plant productivity conditions for the different *Aphthona* species. From this work, they provided a diagnostic framework for the identification of appropriate biological control habitats and key site requisites that might be conducive to the establishment and impact of the biological control agents on U.S. populations of leafy spurge.

GENETIC ADVANCES IN BIOLOGICAL CONTROL

Among the approaches for using natural enemies of target invasive species, classical biological control is the most common strategy. However, advances in genetics now allow for greater precision and predictive power in our understanding and development of biological control for invasive species, particularly insects, and such tools greatly increase the opportunities for managing invasive species (Roderick and Navajas 2003). Genetic engineering or traditional breeding techniques can enhance biological control organisms before their release. The goal of these approaches is to improve host specificity. Despite the potential for using genetic manipulations in biological control development programs, these new technologies still pose a number of challenges that must be addressed by regulators.

CONCLUSION

Biological control has been shown on many occasions to be the most cost-effective invasive species management tool available. However, integrating biological control projects with the full breadth of other IPM tools, expanding post-release monitoring to maximize efficacy, adaptive management, and incorporating new and innovative ecological and genetic technologies may provide private and public land managers greater opportunities for long-term success in suppression of established invasive species.

RECOMMENDATIONS

Recognizing that biological control of widespread established invasive species can be the most cost-effective sustainable control mechanism, particularly as part of an integrated pest management (IPM) program, ISAC recommends:

1. Federal land-management agencies that oversee and conduct control operations utilizing biological control agents should do so in the context of an adaptive IPM strategy by partnering with federal, state, tribal, and local scientists and agencies of relevant pest-management disciplines to improve the effectiveness of biological control agents.
2. Federal land-management agencies should place increased emphasis on post-release monitoring to provide feedback and input to the decision-making process and enhance the success and economic performance of biological control programs. To accomplish this, project funding must be assured for the full duration of the project, as well as the broader framework of the IPM approach.
3. Federal land-management agencies should include long-term stewardship and sustainability of desired ecosystem functions as the ultimate goal of all biological control programs. To this end, IPM programs may include ecological rehabilitation that will provide resilience to the ecosystem and help prevent re-invasion or replacement of one invasive species with another. This will require coordination among many local, state, tribal, and federal agencies, including those responsible for developing the biological control programs and those in charge of resource management.
4. Responsible federal agencies should give increased attention during selection of biological control agents for release to: 1) characterizing natural enemy candidates using morphological taxonomy or genetic markers at the onset of a program, 2) utilizing climatic matching models to accurately determine the most likely areas of successful establishment of candidate agents, 3) understanding biological control agent host-finding behavior and attack rates/efficacy, and 4) recognizing the most relevant habitat characteristics/associations of biological control agents in their place of origin to better predict rates of colonization, spread, and impact in the invaded range.
5. When biological control is used, federal land management agencies should consider utilizing the information made available from the federal regulatory agencies to more effectively implement biological control programs.

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