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Economics of Detection and Control of Invasive Species:
Workshop Highlights

April 30, 2004

Edited by

Won W. Koo
Jeremy W. Mattson

Center for Agricultural Policy and Trade Studies
Department of Agribusiness and Applied Economics
North Dakota State University
Fargo, ND 58105-5636

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Information on other titles in this series may be obtained from: Department of Agribusiness and Applied Economics, North Dakota State University, P.O. Box 5636, Fargo, ND 58105. Telephone: 701-231-7441, Fax: 701-231-7400, or e-mail: cjensen@ndsuext.nodak.edu.

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Abstract

Invasive species are species that are not native to an ecosystem, and when introduced into the new ecosystem, they cause economic or environmental damage. Trade is one way in which these species are introduced into new regions, and as trade increases, the introduction of invasive species also rises. The Center for Agricultural Policy and Trade Studies, North Dakota State University, held a workshop on April 30, 2004 in Fargo, ND, titled “Economics of Detection and Control of Invasive Species” to address these issues. The purpose of this workshop was to present current findings on the subject of invasive species in agricultural trade and to structure the model for an in-depth research project examining this issue. Speakers included experts from the Animal Plant Health Inspection Service and the Economic Research Service of the U.S. Department of Agriculture and from U.S. Customs and Border Patrol, as well as professors of economics from North Dakota State University and other academic institutions. Discussion included the impact of invasive species on agricultural production and trade, the tools used by the U.S. Department of Agriculture and U.S. Customs and Border patrol to detect and control incoming species, and the creation of econometric models to capture and explain these processes and to analyze policy issues. This report contains abstracts from the presentations given at the workshop.

ECONOMICS OF DETECTION AND CONTROL OF INVASIVE SPECIES

edited by Won W. Koo and Jeremy W. Mattson*

INTRODUCTION

Invasive species are species that are not native to an ecosystem, and when introduced into the new ecosystem, they cause economic or environmental harm or harm to human health. Invasive species are primarily introduced into new ecosystems through human actions, whether those actions are intentional or unintentional. Trade is one way in which these species are introduced into new regions. Over the last three decades, the rate of detrimental introductions has increased substantially as a result of increased air travel and trade (Council for Agricultural Science and Technology, 2002). Trade liberalization is resulting in further increases in the volume of international trade, which could cause the introductions of invasive species to continue to rise. Detecting invasive species early can reduce and control eradication costs. The value of early detection has increased as the volume of U.S. imports of agricultural bulk commodities has risen. A study by Pimentel et al. (2000) estimated that approximately 50,000 non-indigenous species in the United States cause major environmental damage and losses totaling approximately $137 billion per year. Simberloff (1996) wrote that about a fourth of this country's agricultural gross national income is lost each year to foreign plant pests and the costs of controlling them.

The Center for Agricultural Policy and Trade Studies, North Dakota State University, held a workshop on April 30, 2004, titled "Economics of Detection and Control of Invasive Species" to address these issues. The purpose of this workshop was to present current findings on the subject of invasive species in agricultural trade and to structure the model for an in-depth research project examining this issue. Speakers included experts from the Animal Plant Health Inspection Service (APHIS) and the Economic Research Service (ERS) of the U.S. Department of Agriculture, as well as professors of economics from North Dakota State University and other academic institutions. Discussion included the impact of invasive species on agricultural production and trade, the tools used by the U.S. Customs Service and the U.S. Department of Agriculture to detect and control incoming species, and the creation of econometric models to capture and explain these processes.

The first session of the workshop included presentations from economists from APHIS and ERS and an inspector from U.S. Customs and Border Protection. The workshop began with a presentation from John W. Green, economist from APHIS in the Centers for Epidemiology and Animal Health. The mission of APHIS is to safeguard U.S. agriculture. Green addressed how APHIS protects U.S. animals and animal products. He identified the elements of safeguarding and trade risk analysis: collection of comprehensive and accurate data; tracking of animals and animal products; development of risk coefficients for use in monitoring and surveillance, allocation of resources, cooperation with livestock organization, and provision of insurance for risk management;

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*Director and Research Assistant, respectively, in Center for Agricultural Policy and Trade Studies, North Dakota State University, Fargo.

disease spread models; and comprehensive economic consequence analysis. APHIS looks at the risk of a disease being exported from a foreign country, which is called the release probability. The exposure probability is the risk of being exposed to the disease if it is imported by the United States. Animal disease modeling is used to plan for outbreaks by predicting resource demands and costs and to determine the most efficient and effective strategies.

C.S. Kim, senior economist from ERS, gave a presentation on the ERS invasive species program. ERS has initiated a program to examine the economic issues related to managing invasive species as the movement of people and products across borders increases. The ERS program examines measures for reducing the economic risks of invasive species for U.S. agriculture while maintaining the economic gains from trade and travel.

Lynn J. Garrett provided information regarding plant protection. Garrett is an agricultural economist at the Center for Plant Health Science and Technology, which is part of the Plant Protection and Quarantine (PPQ) division of APHIS. Garrett noted that the first step in a proactive detection strategy is identification of potential invasive plant pests associated with high risk pathways into the United States. Reactive safeguarding efforts, which are related to emergency situations and eradication programs, are more costly. Garrett contended that public investment in pest detection and management in the United States has traditionally been under-funded and ill-equipped to overcome the economic impact from pests that threaten plant resources.

Also in the first session of the workshop, Nancy Becker gave the perspective of someone from U.S. Customs and Border Protection (CBP), which is part of the Department of Homeland Security. Becker, who is Chief Inspector at Houston Field Operations, discussed the role of CBP in detecting and preventing the entry of injurious pests and diseases into the United States. CBP enforces regulations imposed by other agencies. Becker's presentation covered CBP's organizational structure, information and technology, and methodologies used in detecting, targeting, and preventing the entry of potential invasive species. One approach CBP is employing is to expand borders by detecting and taking care of issues before they reach the U.S. border. Becker gave one example of how invasive species are exported to the United States, showing how difficult it is to stop these species from entering. When tiles are stored in Italy, they are wrapped in cellophane and may be left outside for months. Snails love the cellophane, and various insects get inside it. When the tiles are exported to the United States, these various species come with.

The next two sessions of the workshop focused on economic modeling. C.S. Kim gave another presentation, which focused on public policy for managing invasive species. Kim noted that from a policy standpoint, it is important to develop a conceptual framework for thinking about invasive species. His study develops a conceptual dynamic model to analyze public policy decisions on the budget allocation for managing invasive species and on trade policy in the presence of invasive species.

Larry Leistritz, professor of economics at NDSU, summarized NDSU's research on leafy spurge. Leafy spurge is an exotic, noxious, perennial weed that was first introduced in North America in the 19th century. The weed currently infests large amounts of untilled land in the Plains and Mountain states. Once established, the weed spreads quickly, displacing native vegetation. Leafy spurge can create serious economic losses for land owners and ranchers. Estimating the economic impacts of weed infestations requires consideration of both biological and economic parameters. A bioeconomic model for estimating the impacts of leafy spurge infestations was developed by Leistritz et al. (2004). The study estimated the impact of leafy spurge on grazing land and wildlands. Total impacts (direct plus secondary) for the four-state region were estimated to be \$129.5 million annually. Two alternative approaches to long-term leafy spurge control were evaluated: herbicide treatments and grazing with sheep.

Two papers were presented by Amit Batabyal, professor of economics at Rochester Institute of Technology. These studies, which were coauthored by NDSU economics professor Hamid Beladi, develop a new framework for studying the problem of preventing biological invasions caused by ships transporting internationally traded goods. The ballast water in ships transport a variety of alien plant and animal species from one geographical region to another. The studies by Batabyal and Beladi use a queuing-theoretic model to analyze different inspection regimes.

Following in this report are the abstracts from the presenters at the workshop. The first section contains the summaries from the presentations from APHIS and Customs and Border Protection during the first session of the workshop. The second section has the abstracts from presentations in the second and third sessions of the workshop on modeling the economics of trade and invasive species.

ISSUES AND CONCERNS OF INVASIVE SPECIES

Safeguarding Animal Health

John W. Green[1]

Veterinary Services is a sister agency with Plant Protection and Quarantine Services within the Animal and Plant Health Inspection Service (APHIS). The role of Veterinary Services is to protect and improve the health, quality, and marketability of U.S. animals and animal products. As part of Veterinary Services, the Centers for Epidemiology and Animal Health (CEAH) in Fort Collins, Colorado provide research, data and management information to Area Veterinarians in Charge in every state, management in Washington, D.C., the livestock industry, and U.S. trading partners.

There are three Centers within CEAH: the Center for Animal Disease Information and Analysis (CADIA), the Center for Animal Health Monitoring, and the Center for Emerging Issues. CADIA, where the Risk Analysis Team is located, collects data, builds management information systems, and performs risk analysis on pathways related to foreign animal disease incursions and the export of disease organisms from the United States. There are several elements related to safeguarding and trade risk analysis which are the focus of CADIA:

- Collection of comprehensive and accurate data;
- Tracking of animals and animal products;
- Development of risk coefficients for use in
  - Monitoring and surveillance,
  - Allocation of resources,
  - Cooperation with livestock organizations, and
  - Provision of insurance for risk management;
- Developing and using disease spread models; and
- Providing comprehensive economic consequence analysis.

The Trade Risk Team provides two major types of risk analysis: release assessment and exposure assessment. To perform release assessment, teams of professionals visit foreign countries that have applied to export animals or animal products to the United States. Eleven risk factors are used to assess the risk of an unwanted disease organism reaching the border of the United States. Exposure assessment is then used to evaluate pathways and the risk of disease organisms spreading throughout the country. Alternative scenarios are developed to test control strategies in the event of a disease outbreak.

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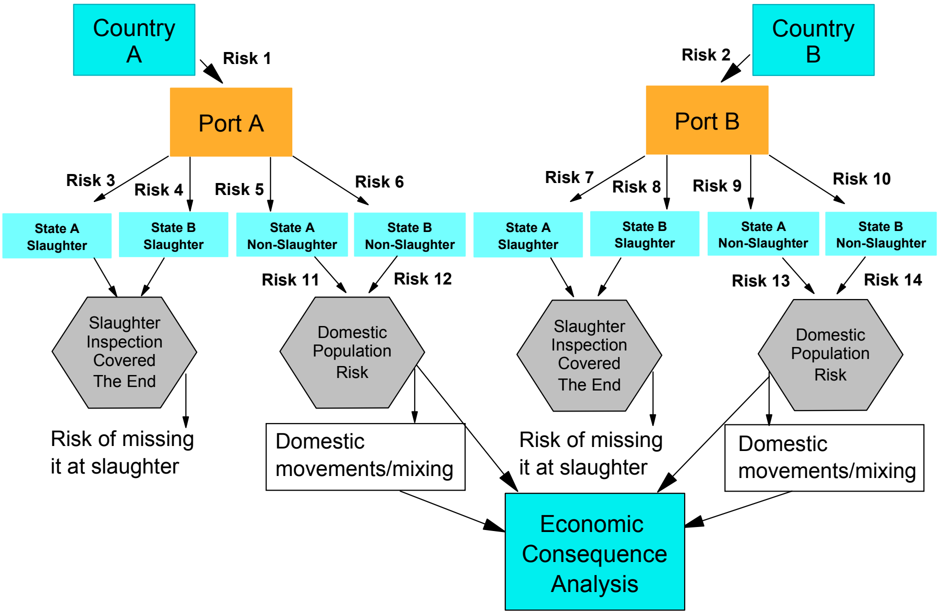
[1] Chief Economist, Trade Risk Analysis Team, Centers for Epidemiology and Animal Health, Veterinary Services, Animal and Plant Health Inspection Service, U.S. Department of Agriculture.


Live Animal Import Exposure Pathway Analyses

The following databases are being developed and expanded within the Center for Animal Disease Information and Analysis to monitor and track animals and animal products within the United States:

- ePermits – permits to import animals and animal products;
- Veterinary Accreditation System – accredited vets are the first line of defense against the spread of animal diseases;
- Interstate Certificates of Veterinary Inspection – health certificates must be signed before animals can be moved from state-to-state;
- Premises and animal identification – all premises containing livestock and all animals must be identified with USDA tags by 2006; databases will be developed to enable 48-hour traceback of a disease animal;
- National animal health laboratory network – all laboratories performing tests for animal diseases will be connected with a database;
- Generalized Data Base – Veterinary Services state-based information system of farm visits and other slaughter plants tests will be enhanced; and
- Management information systems – summarized data will be provided to management to enable more efficient use of resources.

Animal disease spread models are being expanded, working with Canada, to include more species and disease organisms. Spread models are being used to plan for outbreaks by predicting resource demands and costs and determining the most efficient and effective strategies. They are being used in test exercises as predictive models and as input for economic consequence modeling.

Economic consequence modeling is being conducted internally and in cooperation with USDA's Economic Research Service (ERS). The ERS's Strategic Analysis System (SAS-USA) was used to quantify the interstate impacts of the Exotic Newcastle Disease outbreak in the southwest during 2002-2003. It was also used to evaluate BSE scenarios after the Canadian discovery in May 2003 and the Washington state discovery in December 2003.

Invasive species pathways are listed for each disease outbreak which occurs in the United States. Data then are examined to determine whether a quantitative risk assessment can be performed or whether we must be satisfied with a qualitative risk assessment. Pathways vary by disease organism, animal species, and production methods. Although each pathway for each disease varies, there are many common pathways to all diseases. There are legal and illegal pathways. Inspection and enforcement varies by port. There are many ways to accumulate risk over all links of a pathway, and there are many methods to calculate risk along each link of the pathway. Importation of an organism does not necessarily mean that infection and spread is inevitable. There are many ways to allocate resources to minimize the risk of a disease becoming established and spreading. The following table shows the pathways for High Pathogenic Avian Influenza, Food and Mouth Disease, Classic Swine Fever, and Exotic Newcastle Disease, with the pathways ranked from high risk to low risk.

Disease Pathways

High Pathogenic Avian Influenza

(ranked from high risk to low risk)

- Human biological
- Game (fighting) birds
- Illegal human movement
- Fomites (human)
- Mis-manifested shipments
- Contraband/illegal movement or labeling of products
- Shipments from disease-free countries
- Imports from infected or neighboring countries
- Pet birds in home quarantine
- Migratory birds
- Chicken products without inspection certificate
- Packages from UPS, FedX, Postal Service
- Garbage from many sources
- Internet orders and shipments
- Inedible animal products in commercial trade
- Infected conveyances for products
- Birds in transit
- Swine products
- Zoo animals
- Military movements

Foot and Mouth Disease

(ranked from high risk to low risk)

- Contraband meat products
  - (Carried by passengers, in cargo containers, sent by mail, black market)
- Illegal transshipments
- Garbage
  - (From small or commercial boats and from private or commercial planes)
- Edible animal products
- Illegal human movements into the United States
- Other animal-related products
  - (Straw, hay, packing material, crops, feed, farm equipment, shipping containers)
- Legal human movements
  - (Tourists, zoo personnel, animal health workers, livestock brokers, news media, etc.)
- Live animals – zoo, breeding livestock
- Animal germplasm – semen, embryos
- Inedible animal products – pet food, hides, etc.
- Military movements – exercise, flights, veterinarians, etc.

Classic Swine Fever (Hog Cholera)

(ranked from high risk to low risk)

- Movement of live swine
- Refrigerated/preserved carcasses and meat
- Oro-nasal secretions – 2-3 day survival rate for organism
- Untreated garbage
- Airborne movements
- Import of cured meat products
- Semen/ova
- Contaminations (soil, manure) on trucks, etc.
- Insect vectors
- Machinery, veterinary instruments
- Feed, water, etc.

Exotic Newcastle Disease

(in no order)

- Live domestic and wild birds
- Fresh meat and meat products from domestic and wild birds
- Day-old imported birds and hatching eggs
- Products of bird origin
- Virus may be present in secretions and excretions, carcasses, uncooked poultry products, unsanitized table eggs, fertile eggs, etc.

Protecting Against Invasive Plant Pests

Lynn J. Garrett[2]

Public Sector Invasive Species Issue and Concern

An invasive plant pest cannot be detected in a timely manner if no one is looking for it. The first step in a proactive detection strategy is identification of potential invasive plant pests associated with high risk pathways into the United States. Biological data can be collected and used in the development of tools, trapping protocols and effective traps and lures, which are necessary to look for the invasive plant pest. An excellent example of a proactive APHIS-Plant Protection and Quanrantine (PPQ) program is the Pink Hibiscus Mealy bug in the Caribbean.

Reactive safeguarding efforts are related to emergency situations and eradication programs which are more costly. Historically, exclusion efforts have been reactive and focused on inspection at first point of entry. If a pest organism was found infesting a commodity on arrival, measures were taken to destroy the shipment, re-export it, or disinfest it. As the potential harm from invasive plant pests became better understood, more preventative exclusion measures were developed, and the system evolved into the comprehensive plant safeguarding system that is in place today.

Some of the reactive program efforts and associated costs include: Asian Longhorned Beetle, 6 years, $79 million; Citrus Canker, 7 years, $258 million; Karnal Bunt, 7 years, $70 million; Plum Pox Virus, 3 years, $18 million. A recent example of a proactive effort was the Mexican Fruit Fly Quarantine lasting 10 months. (Infestation was discovered Nov. 18, 2002; a quarantine area of over 117 square miles was imposed Dec. 5 and later expanded to 130 sq miles; and the quarantine ended Sept. 23, 2003.) During the quarantine, host material was not allowed to leave the regulated area unless certified. If left untreated, the infestation would have threatened fruit crops worth more than $75 million annually. The cost of the Mexican Fruit Fly Quarantine in FY03 was $10.6 million.

Public investment in pest detection and management in the United States has traditionally been under-funded and ill-equipped to overcome the economic impact from pests that threaten plant resources. A major concern exists in the area of resource allocation among the strategies and activities in the safeguarding continuum. The need to determine the appropriate level of investment in pest detection for effective and efficient use of resources for pest management is needed. Products of such research efforts should yield strategic priorities and the development of general rules, both of which should evolve from the knowledge of needed follow-up activities. The level of investment needs to be compared to the benefit, and the allocation of the investment evaluated by such factors as commodity(s), geographic location, etc.

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[2] Agricultural Economist, Center for Plant Science and Technology, Plant Protection and Quarantine, Animal and Plant Health Inspection Service, U.S. Department of Agriculture.

An effort to evaluate the appropriate level of investment for pest detection in its earliest phases would have several important advantages such as shorter pest eradication programs, less expensive programs, more time to utilize strategies and tools for management, and greater probability of success. Some examples that appear to support this belief include the plum pox virus, the Asian long horned beetle, and spotted knapweed. These are all costly programs that might have been benefited from early detection activities.

Existing efforts to provide early warning of plant pest threats include activities within PPQ such as the New Pest Advisory Group (NPAG) and plant pest lists. NPAG evaluates plant pests occurring elsewhere in the world and determines the U.S. plant resources that may be vulnerable. PPQ has also established several plant pest lists for various purposes and has supported documentation from several national professional scientific societies and other sources. These lists include:

- Regulated Plant Pest List,
- Offshore Pest Information System Target Pest List,
- National Cooperative Agricultural Pest Survey Target Pest List,
- Select Agent List, and
- Global Pest and Disease Database.

A description of these various pest lists is provided at the APHIS website

(http://www.aphis.usda.gov/ppq/pestlist).

Annual Cooperative Agricultural Pest Detection Surveys

Every year, PPQ and cooperators conduct the Cooperative Agricultural Pest Survey (CAPS) in each state to detect potentially threatening exotic pests. The CAPS is a plant pest program that is directed by the early detection facet of the safeguarding continuum. Because the number of potential plant pests is so great, annual selection of the limited list of the most important national CAPS target pests becomes very difficult.

Recently, the Center for Plant Health Science and Technology (CPHST) convened a Working Group to design a robust, transparent process for prioritizing the most threatening pests. This group developed a list of criteria to be used in categorizing national pest threats. Then the group compiled the criteria into a 22-point questionnaire divided into three parts: (1) biological/epidemiological; (2) economics; and (3) agriculture inspection/quarantine.

The Working Group then enlisted subject matter experts to apply the questionnaire to a long list of highly significant pests. The experts - 60 scientists, economists, and operational staff from government, academia, and beyond - volunteered their time and talent to ensure high quality results and provided over 2,000 total answers.

Not all criteria are equally important. The CAPS National Committee met on December 5, immediately following the 2003 Annual CAPS Meeting in Las Vegas, to determine appropriate criteria weights. To do this, a contractor was hired and introduced the Analytical Hierarchy Process. The members used this mechanism to work through pair-wise comparisons for all criteria.

The questionnaire results were then combined for each pest along with the criteria weightings. The end result was an ordered ranking of all pests considered. The National CAPS Committee assessed the results and made necessary adjustments based upon operational considerations. A base has now been prepared and established by experts from the scientific disciplines, economics, and PPQ operations. This process will be used again next year and into the future.

Resources for Early Pest Detection

Any effort to address problems associated with invasive species requires resources to acquire the needed technology and provide for its efficient deployment. As with any public program, past performance is always considered for future increases in resources.

The issue of what management strategy to implement in the safeguarding management system is related to the biology of the pest and the value of the plant resources at risk and the costs of implementing the strategy. PPQ's current paradigm is described below:

> *"While port of entry inspection must continue to play an important role in the exclusion of invasive plant pests, the historic view that this activity can function as the focal point for exclusion must be abandoned. A new risk based management strategy that requires compliance and mitigation of pest risk at origin can reduce risk and enable expedited entry."*

(Safeguarding American Plant Resources -
http://www.aphis.usda.gov/ppq/safeguarding/index.html)

The Role of U.S. Customs and Border Protection

Nancy Becker[3]

U.S. Customs and Border Protection (CBP) plays a role in detecting and preventing the entry of injurious pests and diseases into the United States. CBP became an official agency of the Department of Homeland Security on March 1, 2003, combining employees from the Department of Agriculture, the Immigration and Naturalization Service, the Border Patrol, and the U.S. Customs Service. CBP has a primary mission of detecting and preventing terrorism, but also has the roles and responsibilities in carrying out traditional missions. CBP is responsible for apprehending individuals attempting to enter the United States illegally, stemming the flow of illegal drugs and other contraband; protecting our agricultural and economic interests from harmful pests and diseases; protecting American businesses from theft of their intellectual property; and regulating and facilitating international trade, collecting import duties, and enforcing U.S. trade laws.

In its mission of protecting against harmful pests and diseases, data are collected from the field and from various other sources and are used to conduct pest risk assessments and analysis to identify high-risk pathways for the possible introduction of injurious pests and diseases. The pathway information is then used to query pre-arrival information on cargo and conveyances using CBP's targeting systems to place holds on high-risk cargo. Targeting and inspection programs used by CBP include the Automated Targeting System (ATS), the 24-Hour Rule of October 2002, the Trade Act of 2002, the Container Security Initiative (CSI), the National Targeting Center, Unified Cargo Processing, the USDA Sampling and Tracking System, the Customs-Trade Partnership Act Against Terrorism (C-TPAT), Operation Safe Commerce, the Bioterrorism Act, the Agriculture Bioterrorism Protection Act of 2002, the Beagle Brigade, and the USDA permitting process and requirements for regulated and restricted commodities. CBP is working to expand borders by detecting and taking care of issues before they reach the border.

CBP enforces regulations developed by other agencies. For example, CBP enforces USDA permit requirements. Cargo inspections are perfomed and regulations and requirements are enforced to prevent the entry of injurious pests and diseases. If pests are detected, the cargo will be treated, if possible. If there is no possible treatment, entry is refused.

It is very important for researchers, regulators and enforcers to work together and communicate to help detect and prevent the entry of potential invasive species.

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[3] Chief Inspector, Houston Field Operations, U.S. Customs and Border Protection, Department of Homeland Security.

MODELING THE ECONOMICS OF TRADE AND INVASIVE SPECIES

Public Policies for Managing Invasive Pest Species

C.S. Kim and Jan Lewandrowski[4]

There is a growing interest among federal and state agricultural policy makers to better understand the consequences of alternative policy responses to economic threats invasive pest species pose to food and fiber production systems. Among other factors, there has been a sharp increase in the number of and spending on the set of emergency programs USDA's Animal and Plant Health Inspection Service (APHIS) operates to eradicate and control new outbreaks of invasive pests - recent examples include avian influenza, Karnal bunt, citrus canker, and plum pox. Between 1991 and 1995, these programs numbered 1 or 2 per year with total expenditures averaging about \$10.4 million annually. Between 1999 and 2001, there were between 7 and 10 such programs per year with total expenditures averaging more than \$232 million annually, with a record high \$340 million in 2001.

While there are many ways to group invasive pest species, from a policy perspective it makes sense to distinguish between species that are already in the United States and those that have yet to arrive. This grouping reflects the very different policy considerations involved in assessing how to respond to species that are here and inflicting economic damages and species where the issue is how much damage they could do if they arrive and become established. Specifically, this grouping allows us to look at the allocation of limited invasive species management resources between activities aimed at preventing the arrival of new pests (including additional arrivals of existing pests) and activities aimed at eliminating or reducing the damages done by species that are already here.

In this conceptual review, we develop a dynamic model for managing a generic invasive pest with an uncertain arrival date. We use the model for two purposes. First, we derive economic properties of an optimal allocation of resources between exclusionary and control measures in invasive species management. We use the concept of *discovery* of invasive species rather than *arrival* or *establishment*. The concept of discovery is important because while a species may have arrived and be spreading, if this information is not known the species will be considered not yet present and the policy focus will be on keeping it out. After discovery, the species will be considered a present alien pest and the policy focus will be expanded to include measures aimed at preventing additional arrivals and controlling – and in the extreme, eradicating - the existing population. Discovery of an invasive species does not necessarily imply that invasive species become established. Therefore, we provide an economic property for establishment from our model.

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[4] Economic Research Service, U.S. Department of Agriculture. The views expressed do not necessarily reflect those of the U.S. Department of Agriculture.

The second purpose for which we use our model is to look at the choices of trade policy options for imported goods that have a positive probability of introducing an invasive pest. International agreements related to trade often recognize a country's right to protect itself from actual or potential economic losses associated with biological invasions (examples include the North American Free Trade Agreement and the World Trade Organization's Agreement for Sanitary and Phytosanitary Measures).

The Model

Our framework distinguishes between pre- and post-discovery exclusion activities and between post-discovery exclusion and control activities. That is, exclusionary measures – such as trade restrictions, border inspections, and pest eradication programs in foreign countries – can occur before and after discovery but are distinct resource allocation decisions. Control measures on the other hand – such as restrictions on domestic movement of commodities, seizure and destruction of infested or infected commodities, and applications of biological controls – are only used after a pest is known to be present.

We assume that both the species' population growth rate and the rate of additional – or subsequent – discoveries are known. We note that assuming known rates for population growth and subsequent discoveries imposes nothing in the way of restrictions on our model. In fact, knowing how the growth rate and the rate of additional discovery are affected by economic, biological, and environmental factors significantly extends the applicability of our model.

We use our model to look at the allocation of a budget to manage an invasive pest between exclusion and control measures. More explicitly, we look at the budget allocation for exclusion measures in the periods before and after discovery, and the budget allocation between control measures and exclusion measures in the period after discovery.

The goal of invasive species policies is assumed to be to maximize the present value of the expected net economic benefits associated with the adoption of the exclusionary and control measures subject to the following two conditions. First, discovery of invasive species is stochastic and the rate of discovery declines as the adoption of the exclusionary measures increases, but it increases as the level of imported goods increases. Second, after discovery of an invasive species, the rate of population growth declines with the adoption of control measures. Similarly, the rate of subsequent discovery of an invasive species declines with the adoption of the exclusionary measures and increases as the trade volume increases.

Results and Conclusions

It has been well documented that the economic and environmental impacts resulting from invasive species can be substantial. This study develops a conceptual dynamic model to analyze public policy decisions on the budget allocation for managing invasive species and on trade policy in the presence of invasive species.

Results include the following:

· In concept, the marginal opportunity costs of managing a species after discovery are greater than the marginal opportunity costs of preventing invasive species before discovery of invasive species. This suggests that it is more efficient to allocate more resources to the adoption of exclusionary measures before discovery of an invasive species. From a policy perspective, this means that for species with high hazard rates, all else equal, it is more efficient to focus on exclusion measures before the species is known to exist in the United States than on control and exclusion (aimed at keeping out additional arrivals) after discovery. However, if the marginal opportunity cost of resources is greater than the sum of the rate of time preference and the hazard rate, it is less costly to wait until an invasive species is discovered to act.

· If the marginal opportunity cost of resources after discovery of an invasive species is greater than the ratio of the hazard rate to the rate of time preference, it is more costly to adopt exclusionary and control measures. For this case, an invasive species is considered as not established yet or it is not a pest.

· The expected marginal opportunity costs of exclusionary measures before and after the discovery of the first incidence of an invasive species must equal the expected marginal economic benefits resulting from the reductions of the hazard rate and the rate of additional subsequent discoveries, respectively, for the optimal resource allocation.

· After discovery of an invasive species, the optimal resource allocation requires that the marginal opportunity costs of control measures equal the marginal benefits resulting from the reduction of the species' population growth rate, while the marginal opportunity costs of exclusionary measures equal the expected marginal economic benefits resulting from the reductions of the rate of additional subsequent discoveries.

· Before discovery of an invasive species, if the commodity being imported under free trade conditions is identified to carry a potentially invasive species, the adoption of exclusionary measures would result in an economic loss to domestic consumers and an economic gain to domestic producers.

· The marginal damage of an invasive species associated with imports appears to not be a constant, and therefore, the domestic producer's supply curve rotates from below to the left as a result of damage from the invasive species.

· After discovery, the adoption of exclusionary and control measures would result in an economic loss to domestic consumers greater than before discovery of invasive species. However, whether the net change in producer surplus is positive or negative depends on the magnitude of damage, the elasticity of supply, and the per unit cost of adopting the exclusionary and control measures. In general, some trade-restricting exclusionary measures may be optimal both before and after the discovery of an invasive species, because the benefits of trade may exceed the costs of managing invasive species.

From a policy standpoint, it is important to develop a conceptual framework for thinking about invasive species. As noted in the introduction, the incidence of invasive pest outbreaks and the costs of responding to them have both increased dramatically in the last few years. Hence, the need to respond to these pests is increasing rapidly. Empirical analyses of invasive pests are often hampered by a lack of data – especially for cases where the pest is not yet present. Conceptual models like ours then, can help to formalize the process of thinking about invasive pests (and invasive species in general) and help to ensure that policies for prioritizing and addressing invasive pest problems are consistent and make economic sense.

Leafy Spurge in the Northern Great Plains: Assessing Economic Impact and Economics of Control Alternatives

F. Larry Leistritz, Dean A. Bangsund and Nancy M. Hodur[5]

Issues Addressed

Leafy spurge (*Euphorbia esula* L.), a perennial weed native to Europe and Asia, was introduced to North America in the nineteenth century and has become widely established in the northern Great Plains region of the United States and the adjacent Prairie Provinces of Canada. Leafy spurge has developed into a serious problem for ranchers and public land managers because of its ability to spread rapidly, displacing native vegetation, and sustain itself despite repeated herbicide treatments. The plant spreads by both seeds and rhizomes and is unpalatable to cattle, substantially reducing grazing capacity. Leafy spurge also impacts the value of wildland, which we define as land not classified as urban or built-up, industrial, or agricultural, such as forest, range, or recreation areas. The effects of leafy spurge infestations on wildland outputs result from the ability of the plant to displace existing vegetation and its incompatibility as feed for most ruminant wildlife (e.g., deer, elk). By 1993, leafy spurge was estimated to infest about 1.6 million acres (657,000 hectares) in the four-state northern Great Plains region of Montana, North Dakota, South Dakota, and Wyoming, and decision makers recognized the seriousness of the problem. This paper summarizes research undertaken to (1) evaluate the economic impacts of leafy spurge and (2) analyze economics of leafy spurge control alternatives.

Methodology

Estimating the economic impacts of weed infestations requires consideration of both biological and economic parameters. A bioeconomic model for estimating the impacts of leafy spurge infestations was developed (Leistritz et al. 2004). The evaluation process estimated the impact of leafy spurge on (1) grazing land and (2) wildlands. In each case, the analysis involved estimating the effect of changing levels of leafy spurge infestation on land output (e.g., carrying capacity for cattle, wildlife supported). Then, the changes in biophysical outputs were used to estimate direct economic impacts. Changes in livestock carrying capacity were used to estimate effects on livestock producers (reduced income) and local agribusiness firms (reduced sales/receipts). Similarly, changes in wildlife populations and watershed benefits were used to estimate changes in outdoor recreation expenditures and outlays necessary to mitigate damages from runoff and soil erosion. The secondary economic impacts (i.e., those resulting from the initial or direct effects through the multiplier process) were estimated using input-output analysis. The total (direct plus secondary) economic impacts measure the effects of leafy spurge infestations on the economy of the northern Great Plains region (i.e., reduced incomes of households and receipts of firms in various sectors).

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[5] Professor, Research Scientist, and Research Associate, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo, ND.

Two alternative approaches to long-term leafy spurge control were evaluated: herbicide treatments and grazing with sheep. In both cases, economic evaluation required identifying treatment benefits and costs. First, a deterministic, bioeconomic model was developed to evaluate the economic feasibility of control alternatives. Second, recommended control programs were identified, along with their costs and control characteristics. Finally, plausible treatment scenarios were selected to evaluate the economics of long-term control strategies and to assess the sensitivity of results to changes in magnitudes of control variables (Bangsund et al. 1996).

Findings and Conclusion

Estimating impacts on grazing lands required information on the extent of grazing land in the four-state region, leafy spurge infestations on grazing land, the resulting losses in livestock carrying capacity, and the economic effects of those losses for livestock producers and agribusiness firms. Grazing land was defined as all lands used for grazing of domestic livestock, without reference to land tenure, other land uses, management, or treatment practices. The four-state region has approximately 146 million acres (60 million hectares) of grazing land, of which 1.1 million acres (0.8 percent) were estimated to be infested with leafy spurge, based on a survey of county weed boards (Leitch et al. 1996).

A carrying capacity reduction model was used to estimate the lost forage from leafy spurge infestations. The model indicated that, when leafy spurge infestations reach 80 percent, grazing capacity for cattle is reduced to zero, because cattle typically will not enter dense leafy spurge stands to seek the remaining forage.

The economic impacts of leafy spurge on ranchers and landowners include reduced income from reductions in grazing capacity and lost livestock sales. In 1993, the grazing capacity lost to leafy spurge in the four-state area would have supported a herd of about 90,000 cows, resulting in about \$37.1 million in annual livestock sales, \$10.7 million in annual income for ranchers and landowners, and \$26.4 million in livestock production expenses (receipts for agribusiness firms).

The economic impacts of leafy spurge on wildland were estimated from changes in wildlife habitat and reductions in soil and water conservation benefits. The four-state region has about 68 million acres of wildland, of which 0.5 million (0.8 percent) were estimated to be infested with leafy spurge (Leitch et al. 1996). These infestations were estimated to reduce wildlife-related recreation expenditures by \$2.4 million annually and watershed benefits by \$1.0 million annually.

Secondary economic impacts were estimated using input-output analysis. The input-output model used in this study has 17 sectors and is based on primary (survey) data from firms and households. The model is closed with respect to households (i.e., the household sector is included within the model and estimates of economy-wide personal income are provided).

To summarize, the direct economic impacts of leafy spurge on grazing land were estimated to total \$37.1 million annually, while the direct impacts of leafy spurge on wildland totaled \$3.4 million. Thus, the total direct economic impact of leafy spurge infestations was more than \$40 million annually. The secondary impacts of leafy spurge infestations on grazing land were estimated to be $82.6 million annually, or about $2.23 per dollar of direct impact. Secondary impacts of wildland infestations were estimated to be $6.4 million annually, or $1.88 per dollar of direct impact. Total impacts (direct plus secondary) for the four-state region were estimated to be $129.5 million annually.

The economic feasibility of fifteen herbicide treatment alternatives to control leafy spurge was evaluated (Bangsund et al. 1996). The treatment alternatives were those then being recommended for leafy spurge control on grazing land. The analysis led to several findings.

1. Some treatments would never be recommended, based on economic criteria, as alterative herbicide programs would always provide similar levels of control at a lower cost.

2. Broadcast herbicide treatment may result in positive net returns, particularly for small infestations on productive grazing land.

3. Treating the perimeter to prevent patch expansion is economically viable in some situations when treating the entire infestation is not economically justified.

Similar analyses were undertaken for sheep grazing as a leafy spurge control measure (Bangsund et al. 2001). Sheep grazing was most economically attractive in situations with high rangeland productivity, low fencing expense (e.g., large pastures), and high flock proficiency (e.g., high lambing rates and market weights).

The results of the economic impact study were widely disseminated to decision makers at federal, state, and local levels. The findings indicated not only the substantial economic losses associated with current levels of leafy spurge infestations, but also the potential for even greater future impacts if the spread of leafy spurge continued at past rates. The results also clearly indicated that economic losses from leafy spurge infestations were not confined to agricultural producers and landowners. Rather, the secondary economic impacts (which accrue primarily to the trade and service sectors of the regional economy) substantially exceeded the direct impacts.

At state and local levels, the results of both economic impact and economics of control analyses were presented to state weed control association meetings, county weed boards, and legislative committees. In some cases, these groups subsequently allocated additional resources for leafy spurge control efforts. Study results were also used to help justify implementation of a substantial biological control effort for leafy spurge (Bangsund et al. 1999).

International Trade and Biological Invasions: A Queuing Theoretic Analysis of the Prevention Problem[6]

***Amitrajeet A. Batabyal*[7] *and Hamid Beladi*[8]**

In this age of globalization, there is increasing mobility of both humans and goods between countries and continents. Ships are routinely used to transport a variety of internationally traded goods between different countries. There is no gainsaying the fact that this international trade in goods is generally beneficial for the countries involved. Indeed, there are several results in modern trade theory which show that voluntary goods trade between nations is welfare improving for all the nations involved.

This notwithstanding, as Heywood (1995), Parker *et al.* (1999), and others have pointed out, in addition to transporting goods between countries, by means of their ballast water, ships have also unwittingly transported all kinds of non-native—also referred to as exotic or invasive—plant and animal species from one geographical region to another.[9] These non-native or alien species have often been very successful in invading their new habitats and the resulting biological invasions have proved to be very costly to the countries in which these new habitats are located. For the United States alone, the magnitude of these costs is astounding. For instance, according to the Office of Technology Assessment (OTA (1993)), the Russian wheat aphid caused an estimated $600 million worth of crop damage between 1987 and 1989. More generally, Pimentel *et al.* (2000) have estimated the total costs of all non-native species to be around $137 billion per year.

It is important to understand that in addition to economic costs, invasive species also cause significant ecological damage. As Vitousek *et al.* (1996) and de Wit *et al.* (2001) have noted, non-

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[7] Department of Economics, Rochester Institute of Technology, 92 Lomb Memorial Drive, Rochester, NY 14623-5604, USA. Internet aabgsh@rit.edu

[8] Department of Agribusiness and Applied Economics and Center for Agricultural Policy and Trade Studies, North Dakota State University, Fargo, ND 58105, USA. Internet hamid.beladi@ndsu.nodak.edu

[9] The principal method of marine non-native species introduction is by means of the dumping of ballast water. Cargo ships typically carry ballast water in order to enhance maneuverability and stability when they are not carrying full loads. When these ships come into port, this ballast water must be discharged before cargo can be loaded. It is estimated that over 4000 species of invertebrates, algae, and fishes are being moved around the world in ship ballast tanks every day. Focusing on just one country, it has been estimated that as much as 13 billion gallons or 50 million metric tonnes of overseas ballast water enters Canadian coastal ports every year. A recent study by the Smithsonian Environmental Research Center (SERC) in Edgewater, Maryland calculated that a liter of ballast water typically contains several billion organisms similar to viruses and up to 800 million bacteria. For more details on these issues, go to http://www.fundyforum.com/profile_archives and to the SERC web site www.serc.si.edu

native species can alter ecosystem processes, act as vectors of diseases, and diminish biological diversity. In this regard, the work of Cox (1993) tells us that out of 256 vertebrate extinctions with a known cause, 109 are the result of biological invasions. Even a single invasive species can cause tremendous damage. Savidge (1987) tells us that following an invasion of Guam by the brown tree snake, all twelve of this island's bird species became extinct.

The point of this discussion is clear. Biological invasions can be and frequently have been a huge menace to society. Given this state of affairs, one can ask what economists have contributed to increasing our understanding of the regulation of biological invasions. Unfortunately, the answer is not much. Although very recently economists have begun to address this question, it is still the case that "the economics of the problem has...attracted little attention" (Perrings *et al.* (2000, p. 11)).

From a regulatory perspective, there are a number of actions that one can take to deal with the problem of biological invasions. It is helpful to separate these actions into pre-invasion and post-invasion actions. Pre-invasion actions relate to the so-called prevention problem. The idea here is to take actions that will effectively prevent a potentially damaging non-native species from invading a new habitat. In contrast, post-invasion actions involve the optimal control of one or more non-native species, given that the species has already invaded a new habitat.

Most economic analyses of the regulation of biological invasions have focused on the desirability of alternate actions in the post-invasion scenario. We now briefly discuss four representative studies. Barbier (2001) shows that the economic impact of a biological invasion can be determined by studying the nature of the interaction between the non-native and the native species. He notes that the economic impact depends on whether this interaction involves interspecific competition or dispersion. Eiswerth and Johnson (2002) analyze an optimal control model of the management of a non-native species stock. They show that given presently available scientific information, the optimal level of management effort is sensitive to ecological factors that are species and site specific and stochastic. Olson and Roy (2002) have used a model of a stochastic biological invasion to examine conditions under which it is optimal to eradicate the non-native species and conditions under which it is not optimal to do so. Finally, Eiswerth and van Kooten (2002) have shown that even when hard data about the spread of an invasive species are unavailable, it is possible to use information provided by experts to formulate a model in which it is optimal to not eradicate but instead control the spread of an invasive species.

The above studies have certainly increased our understanding of regulatory issues in the post-invasion scenario. This notwithstanding, to the best of our knowledge, the only paper that has formally analyzed the prevention problem, i.e., the regulation of a potentially damaging non-native species before invasion, is Horan *et al.* (2002). These researchers model non-native invasive species as a form of "biological pollution." They then compare the properties of preventive management strategies under full information and under uncertainty. Our paper is different from this paper in three important ways. First, we are not interested in comparing the properties of management strategies under full information and under uncertainty. In this regard, we suppose from the beginning that uncertainty is an integral component of the prevention problem confronting a regulator. Second, we use queuing theory—to the best of our knowledge for the first time—to provide a long-run perspective on the stochastic setting in which our regulator operates. Finally, we use aspects of this stochastic setting to set up objective functions that our regulator optimizes.

In this paper we developed what we believe is a new framework for studying the problem of preventing biological invasions caused by ships transporting internationally traded goods between countries and continents. This new framework allowed us to study the problem of preventing a biological invasion from a long-run perspective. Specifically, we first characterized two simple regulatory regimes as two different kinds of queues. We then showed how a publically owned port manager's decision problem can be posed and analyzed as an optimization problem using queuing theoretic techniques. Finally, we compared and contrasted the optimality conditions arising from our examination of the M/M/I/U and the M/M/I/I inspection regimes.

The analysis contained in this paper can be extended in a number of directions. In what follows, we suggest two possible extensions of this paper's research. First, the reader will note that we analyzed Markovian inspection regimes in this paper. As such, it would be useful to investigate the properties of more general inspection regimes in which either the arrival of ships or the service times of inspectors are characterized by general distribution functions. Second, on the numerical front, it would be useful to compare the approach of this paper—in which the optimal number of inspectors choice problem is viewed as a continuous choice problem—with an alternate approach in which this choice problem is cast as an integer programming problem. Studies of international trade driven biological invasions that incorporate these aspects of the prevention problem into the analysis will provide additional insights into a phenomenon that has frequently proved to be very costly for the involved parties.

Maritime Trade, Biological Invasions, and the Properties of Alternate Inspection Regimes[10]

Amitrajeet A. Batabyal,[11] Hamid Beladi,[12] and Won W. Koo[13]

Maritime trade accounts for a significant proportion of total international trade in the world. Ships are the key vehicle in maritime trade and, today, ships are commonly used to transport a whole host of goods between different countries. However, as Heywood (1995) and Parker *et al.* (1999) have pointed out, in addition to transporting goods between countries, ships have also managed to transport—in their ballast water—a variety of alien plant and animal species from one geographical region to another. Invasive species give rise to economic costs and to biological damage.

Although social scientists have, very recently, recognized the salience of the problem of biological invasions, it is still true that "the economics of the problem has...attracted little attention" (Perrings *et al.* (2000, p. 11)). Consequently, our knowledge of the economics of biological invasions in general and the regulation of biological invasions in particular is very incomplete. Now, from a regulatory standpoint, there are several actions that a regulator can take to grapple with the problem of biological invasions. Following Batabyal and Beladi (2004), it is helpful to separate these actions into pre-invasion and post-invasion actions. The point of taking pre-invasion actions is to prevent alien species from invading a novel habitat. Therefore, the reader should think of *pre-invasion* actions as essentially *preventive* in nature. In contrast, post-invasion actions involve the optimal control of an alien species, given that this species has already invaded a novel habitat.

The small extant literature on the economics of biological invasions has, for the most part, addressed the desirability of actions in the *post-invasion* scenario. To the best of our knowledge, only two papers have theoretically studied the prevention problem, that is, the regulation of a potentially damaging alien species before invasion. These two papers are Horan *et al.* (2002) and Batabyal and Beladi (2004). There are two key differences between our paper and Horan *et al.* (2002). First, we do not compare the attributes of management strategies under full information and under uncertainty. Second, we use a simple queuing-theoretic model to shed light on the properties of two inspection regimes that embody different ideas about the economic cost from regulatory activities.

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[11] Department of Economics, Rochester Institute of Technology, 92 Lomb Memorial Drive, Rochester, NY 14623-5604, USA. Internet aabgsh@rit.edu

[12] Department of Agribusiness and Applied Economics and Center for Agricultural Policy and Trade Studies, North Dakota State University, Fargo, ND 58105, USA. Internet hamid.beladi@ndsu.nodak.edu

[13] Department of Agribusiness and Applied Economics and Center for Agricultural Policy and Trade Studies, North Dakota State University, Fargo, ND 58105, USA. Internet wkoo@ndsuext.nodak.edu

This paper, which is closely related to Batabyal and Beladi (2004), studies optimization problems arising from the steady state analysis of two multi-person inspection regimes. Although this paper does say something about alternate inspection regimes, it does not say anything about the following central question that we analyze in the present paper: When attempting to prevent a biological invasion by inspecting the ballast water of ships, is it a better idea for a port manager to have a *small* number of inspectors inspect arriving ships *less* stringently or should this manager have a *large* number of inspectors inspect the same arriving ships *more* stringently? We use a simple queuing-theoretic model to show that the answer to the above question depends on the port manager's criterion function. In particular, we focus on two different criteria and show that in one case it makes more sense to have a small number of inspectors inspect arriving ships less stringently and in the other case it is more advantageous to have a large number of inspectors inspect arriving ships more stringently.

Maritime trade in goods by means of ships often results in injurious invasions of new habitats by alien plant and animal species. Consequently, if an appropriate authority such as a port manager's objective is to prevent biological invasions, then this manager must inspect arriving ships for potentially deleterious biological organisms. Given this state of affairs, what kind of inspection regime should this manager have in place? In particular, is it a better idea for this manager to have a *small* number of inspectors inspect arriving ships *less* stringently or should this manager have a *large* number of inspectors inspect the same ships *more* stringently? Our analysis shows that if decreasing economic cost is significant, then it makes more sense for the port manager to choose the inspection regime with fewer inspectors and less stringent inspections. On the other hand, if reducing the damage from biological invasions is more salient then the manager ought to pick the inspection regime with more inspectors and more stringent inspections.

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