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The Economic Impacts of Aquatic Invasive Species: A Review of the Literature

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Abstract:

Invasive species are a growing threat in the United States, causing losses in biodiversity, changes in ecosystems, and impacts to economic enterprises such as agriculture, forestry, fisheries, power production, and international trade. The costs of preventing and controlling invasive species are not well understood or documented, but estimates indicate that the costs are quite high, in the range of millions to billions of dollars per year. EPA's Office of Water needs to develop a national estimate of the costs of aquatic invasive species and the benefits of control. This review of the economic literature on invasive species is the first stage in the development of that estimate. The review includes studies on fish, mollusks, crustaceans, invertebrates, and plants. There are few theoretical, and even fewer empirical, studies dealing with the economic costs of aquatic invasive species. Due to the high level of invasions in the Great Lakes, a number of studies focus on species found there, and on Zebra Mussels in particular. The aquatic studies reviewed show values ranging from several hundreds of thousands of dollars a year to tens of millions of dollars a year. It seems apparent that a systematic approach is needed to develop a consistent method to estimate such costs. As the literature points out, invasive species and their control have definite public good aspects and thus call for some level of government intervention. However, to what extent and what form that intervention takes place depends on myriad of issues associated with both the region and the species involved. Optimal policy appears to be as unique as the individual species or ecosystem it is attempting to control and protect.

Key Words: Aquatic Invasive Species, Costs, Literature Review
Subject Matter Categories: Marine/Coastal Zone Resources, Economic Damages/benefits, Biodiversity

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Introduction

Invasive species are a growing threat in the United States, causing losses in biodiversity, changes in ecosystems, and impacts to economic enterprises such as agriculture, forestry, fisheries, power production, and international trade. An 'invasive species' is a species that is "1) non-native to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health" (Executive Order 13112, Appendix 1, 1999)[1]. Not all non-native or non-indigenous species (NIS) become, 'invasive'. Some fail to thrive in their new environment and die off naturally. Others survive, but without destroying or replacing native species. Most introduced species do not meet the standards defined in Executive Order 13112 as 'invasive' (NISC 2000). However, those that do meet the definition have the ability to cause great harm on the ecosystem. About 400 of the 958 species listed as threatened or endangered under the Endangered Species Act are considered to be at risk primarily because of competition with, and predation by, invasive species (Wilcove et al. 1998).

The means and routes by which species are introduced into new environments are called 'pathways'. Some species that become invasive are intentionally imported, and escape from captivity or are carelessly released into the environment. Other invasives are unintentionally imported, arriving through livestock and produce, or by transport equipment such as packing material or a ship's ballast water. Fish and shellfish pathogens and parasites have been introduced unintentionally into the U.S. in infected stock destined for aquaculture. Crates and containers can harbor snails, slugs, mollusks, beetles

[1] For a full description of the Executive Order see http://www.invasivespecies.gov/laws/main.shtml.

and other organisms. Military cargo transport may also harbor unintended species. Stimulated by the expansion of the global transport of goods and people, the numbers and costs of invasive species are rising at an alarming rate (NISC 2001). The cost to preventing and controlling invasive species is not well understood or documented, but estimates indicate that the costs are quite high, in the range of millions to billions of dollars per year (OTA 1993, Pimental et al. 2000). EPA's Office of Water is interested in developing a national estimate of the costs of aquatic invasive species and the benefits of control. This review of the economic literature on invasive species is the first stage in the development of that estimate.

Both theoretical and empirical studies are included in this review. In general, the review was limited to studies dealing with aquatic or aquatic related species and does not include estimates of the costs of invasive agricultural weeds and other purely terrestrial species. Studies dealing with the general economic aspect of the problem are included even if they do not focus on aquatic species per se. Many of the studies focus on aquatic invasive species in the Great Lakes, due to the large amount of ship traffic and corresponding potential for invasion from ballast water. Since the 1800's, over 145 nonindigenous aquatic species have become established there, including 24 species of fish, 9 mollusks, and 61 species of plants (Dohnahue, 1999; Horan and Lupi 2004).

General Cost Studies

There are two studies which tried to estimate the total cost of invasive species in the United States. The first is "Harmful Non-Indigenous Species in the United States" by the Office of Technology Assessment of the U.S. Congress (1993). It details both the ecological impacts and estimated economic impacts of those invasive species considered harmful, rather than all invasive species inhabiting the nation. It also considers native U.S. species outside of their natural ranges as invasive. Over the period examined in the report (1906-1991), 59% of introduced species to the US have caused economic or ecological harm. The report estimated the total cost of damages related to 79 harmful species to be $97 billion, with a 'worst case' scenario total cost of $137 billion. The $97-137 billion estimate is the cumulative cost of invasive species to agriculture, forestry, fisheries and other water uses, utilities, buildings and natural areas.

For aquatic invasives, OTA considered 111 species of fish (88% of total known invasives) and 88 mollusks (97%). Of the 76 fish species intentionally introduced, 35 have caused harm and of the 26 unintentionally introduced in the U.S. 10 species are considered invasive according to the report. For mollusks, 5 out of 10 intentionally introduced and 27 of the 67 unintentionally introduced species have caused harm. Of those considered, 4 fish species and 15 mollusk species had high negative impacts. The list of high impact aquatic species include the Sea lamprey, Zebra Mussel, and Asian clam. OTA estimated that the cumulative loss to the U.S. for the period 1906-1991 for 3 harmful fish species was $467 million (1991 dollars) and $1,207 million for 3 aquatic invertebrates. In terms of aquatic or riparian plants, high impact species include the Salt Cedar, Purple Loosestrife, Melaluca, and Hydrilla. OTA reports that spending on control of aquatic plants in the U.S. is $100 million per year.

Pimentel et al. (2000) produced a more recent study, attempting to update and expand these costs estimates. At the time of the OTA study, they estimated the total number of harmful species in the U.S. to be 4,500. Pimentel et al. (2000) estimated 5,000 and by 2004 that estimate had increased to over 6,000 (Burnham 2004). Invasive weeds are spreading and invading approximately 700,000 ha/yr of U.S. wildlife habitat (Pimentel et al.. 2000). Examining a series of case studies, the Pimentel study estimates the total economic damages and associated control costs for the U.S. due to "harmful non-indigenous species" is $138 billion *annually*. They attribute their higher estimate (*vis a vis* the OTA study) to the broader base at which they look and the increase in the economic cost estimates available for many invasive species. However, they also characterize their cost estimates as low because the study does not take into account the extensive ecosystem damage caused by these species.

The Pimentel study has a number of flaws. First, the methods applied to estimating costs are anecdotal in nature. No systematic empirical methods of estimating costs, which would have provided a statistical basis to judge the validity of the estimates, were applied. There was also no attempt to incorporate ecosystems services. Finally, there was no explicit consideration of the potential benefits provided by some of these invasive species (such as the recreational benefits from introduced game fish). While the effects arrived at by Pimentel are widely cited, these flaws tend to undermine the credibility of the numbers. Both the OTA (1993) and the Pimentel et al. (2000) studies illustrate the difficulty in quantifying the harm done to both the economy and the ecosystem by invasive species. Both studies point to the lack of data available to adequately estimate costs that would help put the problem in some perspective. In a further study, Pimentel et al. (2001) look at the impact of invasive species on 6 countries, including the United States, stating that over 120,000 NIS have invaded these regions at estimated costs of over US$314 billion per year in damages. For the U.S., they report estimated US$1 billion a year in environmental losses alone from introduced fish, US$2.13 billion from arthropods and US$1.3 billion from mollusks.

Government spending on invasives may be a further guide in estimating costs. In 1999/2000, the federal government spent $459 million and $556 million respectively for invasive species activities. For fish and aquatic invertebrates, $20.4 million in federal funding was given out in 1999 (GAO, 2000). The U.S. Geological Service Aquatic Nuisance Species Program had a $5.5 million budget for the National Biological Research Division's Invasive Species Program. The U.S. Coast Guard has a total of $4.5 million annually for invasive related activities, mostly focused on ballast water programs and surveys (Sturtevant and Cangelosi, 2000).

Theoretical Economic Research and Models

Very few studies dealing with invasive species exist in the formal economics literature. Of those that are available, they primarily concentrate on theoretical considerations with relatively little empirical analysis. A number of papers concentrate on issues related to trade. Others develop models of the risk of invasive species or incorporate both ecological and economic models.

Evans (2003) lays out the economic dimensions of invasive species and why economics is increasingly called upon to understand the issues. The causes of biological invasions are often related to economic activities and furthermore, the economic consequences of invasives are broader than just direct control costs and damages. The economic impacts of trade barriers that attempt to prevent an invasive species from entering the U.S. are becoming more complicated. Economic modeling expertise is important for understanding the issues involved. Economic models of the value of nonmarketed environmental and health effects can also be called upon to understand many of the impacts of invasives, beyond control costs. Evans notes that the impacts of invasives can be classified into 6 types: production, price and market effects, trade, food security and nutrition, and financial costs.

Perrings et al. (2002) frame the issue of control of invasive species as a public good and discuss why both the causes of invasive species and the solutions are primarily economic in nature. They point out that the full economic costs of invasive species include the effects on native ecosystems and the human populations that depend on such ecosystems, and are not limited to just the damage or control costs. The authors point out that little investigation has been done into the economic and social causes of biological invasions, which are often the result of decisions related to , land use and conversion of habitat , the use of certain species in production or consumption, and global movement of people and products. Economic drivers such as property rights, trade rules, and prices often influence these decisions. Human behavior influences the probability of invasives becoming established as well as their spread, specifically how people respond to the threat of invasives by either mitigation or adaptation. The control of the risk of invasives has a public good element, in the sense that the benefits of control are neither rival nor exclusive. In other words, control can protect one person or group without excluding those benefits on another or reducing the benefit implying the need for government involvement. Further, effective control of invasives is only as good as the weakest provider of control. If even one nation or state does not provide adequate control, a species can spread and cause damage to all. This argues for a coordinated response among affected parties, both the sources and recipients of the invasive species.

Shogren (2000) addresses the issue of incorporating economics into risk reduction strategies for invasive species using a model of endogenous risk. The model represents the choices available to a policy maker regarding the allocation of resources to reduce the risk of invasive species by both mitigation and adaptation. Throughout the paper, the point is made that economics should be included in risk assessment to improve the effectiveness of such assessment. The study finds that a higher risk of invasive species increases adaptation, but the effect on mitigation depends on whether or not mitigation and adaptation are substitutes or complements. The paper does not provide any empirical examples.

Horan et al. (2002) address the appropriate level of preinvasion control of invasive species and show how decisions can be made both when full information is available and when there is a high degree of uncertainty about invasions. They start with the premise that decision models based on standard economic expected utility theory provide little guidance in the case of invasive species. This occurs because of the probabilities associated with invasions; they exhibit both a low probability of occurring, but often have catastrophic consequences when they do occur. Expected utility theory is insensitive to this type of risk. Risk management models are thus better suited for analyzing strategies of preinvasion control. They set up two models, one under full information and one under ignorance. The first, the risk-management model, assumes that firms are potential carriers of an invading species. Each firm makes choices on production and biosecurity control. Based on its choices, and environmental conditions, there is some probability that a species will be introduced and will successfully invade the new ecosystem. Invasions from one firm are independent of those from other firms. The probability of invasion increases with the number of firms and decreases with biosecurity measures. The model minimizes the expected social cost of invasions and control using the cost of control and the expected damages of invasion. At the optimal level of control, the marginal cost of taking a control action equals the marginal expected benefits, as measured by the reduction in damages. The risk of invasion and damage impact this marginal level of expected damages. This model assumes, however, that the risk of invasion (the probability of invasion given choices of firms) is known.

In the second model described, the risk is unknown, and uncertainty and ignorance of the risk is explicitly modeled. The model assumes that a decision maker will focus on those potential outcomes that will come as the least surprise. The model also assumes that costs and expected damages are minimized, but some of the conclusions differ from the previous model. When uncertainty is present, more resources should be devoted to high damage events that are considered more certain even with a low probability, and less resources to those events considered less likely to happen regardless of the amount of damages. While the risk management model supports firm specific levels of control, the uncertainty model advocates that control be spread equally across firms, thus supporting most current policies that are based on uniform mandated technologies.

Thomas and Randall (2000) look at the role information and revocability play in NIS management by focusing on intentional releases. Usually the protocol is to follow an ex ante approach to fully elucidate the issue before proceeding. Ecologists argue against introductions until the full spectrum of implications are understood via the collection of more and better ex ante information. However, there is no guarantee (and indeed an almost certainty) that enough information will ever be collected. In addition, it is often costly and a "seemingly endless effort" to gain more information. A second approach is to allow only revocable releases. Assuming that marginal costs of damage avoidance are increasing in both approaches, ex ante full information and revocability, the paper argues that improvement in the current procedures could be made by paying a little less attention to ex ante information and more to revocability.

By combining the concept of revocable actions and incentive compatible behaviour, Thomas and Randall present a protocol that first identifies the potentially affected parties and implements a Coasian liability principle when the affect parties are known and property rights clearly established. This involves the establishment of an independent oversight authority and an insurance scheme for both public and private interests wishing to intentionally release non-native species. When the affected parties are large in number and/or dispersed, the protocol suggests a limited role for the oversight authority to act on behalf of affected parties. The authority would deny permits to releasing agents that fail to post bonds sufficient to compensate in worst-case damage scenarios. The oversight authority may decide to permit a methodical step-by-step process of controlled releases designed to make maximum feasible use of revocability and learning-by-doing. Starting with a very small, tightly controlled revocable release and thorough review of the results, each subsequent step would involve larger releases, less rigid controls and lower levels of revocability. The process would terminate as soon as the prospect of a sufficiently harmful outcomes merged with a high probability the harmful outcome could be avoided. The success of such an approach is less dependent on reliable prediction of the consequences of a release based on ex ante information, and more on precommittment to avoid irrevocable actions. Moral hazard is avoided by the establishment of an independent oversight authority to make permitting decisions and the ex ante assignment of liability to releasing agents.

Eiswerth and van Kooten, (2002) apply a stochastic optimal control model for invasive plant species given the uncertainty surrounding the ability to determine efficient management strategies for any given NIS. Sources of uncertainty regarding relevant state variables include paucity of data, measurement errors, and substantial variability in intrinsic rates of spread. This means that invasions possess the properties associated with fuzzy sets and are thereby subject to analysis through fuzzy membership functions. They employ insights from expert panels to develop spread and damage estimates caused by invasive plants. Then , similar to Leung et al. (2002), they employ the stochastic dynamic programming model to identify economically optimal management choices from a portfolio of potential options with the results compared to those of a program that seeks to eradicate the invasive.

Eiswerth and van Kooten apply their model on the decision making process of agricultural producers faced with harmful invasion of the weed, yellow star thistle (YST). Each producer wants to maximize the present value of future stream of net revenues. The expert panel focused on three potential agricultural land uses; grazing on rangeland, grazing on pastureland, and harvest of hay from pastureland. As the productivity of the land increases, the optimal weed management strategy gravitates toward more expensive options. For rangelands offering lower productivity, the optimal strategy is to apply chemicals, or to have no control at all. At the other end of the spectrum, it is optimal to apply more expensive technologies to irrigated pasture that affords both harvested hay and summer grazing. They conclude by stating that decision making under uncertainty where experts can provide only linguistic descriptors of the growth of the invasive species and its potential damages can be beneficial when hard data are unavailable.

Bioeconomic Models

Knowler and Barbier (2000) develop a model of an invasive species when there is competition between the invader and a native species in a given ecosystem. The two principles of their model are that the effects of the invader depend on the exact nature of the interaction and that the correct comparison for determining effects is an ex-ante and ex-post invasion scenario. Their model can accommodate diffusion, competition, or predation and is applied to a case study of the effects of a comb-jelly in the Black Sea on a traditional anchovy fishery. Using the model, they show a decline in profits due to the introduction of the comb-jelly. Barbier (2001) presents the same model as in his earlier paper, but without the case study.

Leung et al. (2002) develop a quantitative bioeconomic model that can evaluate risks and quantify relative benefits of prevention and control strategies for invasive species. The model determines an acceptable level of risk and the impacts on optimal investments. As in earlier papers, the authors point out that risk analysis of invasives is inherently an interdisciplinary problem and requires both economics and ecological expertise. The model is a stochastic dynamic programming model that allows both ecological and economic factors to simultaneously determine the results on social welfare. Both market and non-market values can be included. The model was applied to the case of Zebra Mussels inhabiting a single lake in the Midwest. Under different scenarios results show that the time frame of the analysis mattered in determining an optimal strategy of prevention and mitigation. For a given probability of reducing invasions, the model can determine society's willingness to pay for which the prevention costs equal the benefits of prevention. However, the model did not include nonmarket benefits, was risk-neutral, and did not model multiple invasions simultaneously, all of which would be more realistic.

Settle and Shogren (2002) model the interaction between native Cutthroat Trout and introduced Lake Trout in Yellowstone Lake. Lake Trout prey on Cutthroat Trout along with grizzly bears, birds of prey, and humans. These interactions are incorporated into an ecological-economic model that provides a comparison of optimal policy action with current policies for removing Lake Trout. Humans obtain benefits from the populations of both fish species as do other non-fish species via harvesting fish, catch and release fishing, and nonconsumptive uses, such as wildlife viewing. The model assumes there also exists another composite good for which humans derive benefit that does not depend on any of the species in Yellowstone. The management agency, the National Park Service in this case, has a fixed budget to spend on one or both of the trout species along with other non-species related goods (such as road improvements). It seeks to maximize the net benefits of visitors given this budget. The Park Service will optimally choose a policy that equates the marginal benefit from spending a dollar on removing Lake Trout with the marginal benefit of improving other park resources (such as roads) based on the dynamics of the species population interactions and the benefits derived from visitors. Three scenarios are considered based on the model both with and without accounting for the feedback between the economic and ecological model components. The feedback arises from fishermen's behavior, as they adjust their catch based on Cutthroat Trout population size (with less catch when population declines). In the best case scenario, Lake Trout are eliminated right away and with little cost. The populations of Cutthroat Trout stabilize at 2.7 million without any feedback and stabilize at 3.4 million with feedback. Under the worst case scenario, Cutthroat Trout populations decline to almost zero, with no feedback and to 1 million with feedback. The current policy is between these two cases, with around 1.8 million to 2.4 million Cutthroat Trout without and with feedback. Specifying discount rates and existence values for trout, an optimal large scale Lake Trout control program can be created for $169,000.

Another paper that looks at invasive management policy incorporating economic consideration is Olson and Roy (2002). The analysis examines the economics of controlling a biological invasion whose natural growth and spread is subject to environmental disturbances, outlining conditions under which it is optimal to eradicate versus conditions under which eradication is not optimal. They show that the growth of the invasion and the associated level of disturbance that leads to slowest expansion plays a critical role. Marginal damages at each point in the future are determined by multiplying the compound annual growth rate by a unit of the species today. The marginal benefits of control are the expected discounted sum of marginal damages that are incurred if the species is not controlled. The results capture the stochastic nature of the problem by incorporating both the worst environmental disturbance and the mean of the disturbances in the analysis.

The first result of Olson and Roy establishes that if the marginal costs of eliminating an arbitrarily small invasion are less than the damages from such an invasion, compounded indefinitely at a rate equal to the discounted expected growth of the invasions, then complete eradication is optimal. However, if the damages from an arbitrarily small invasion are less than the marginal costs of removing the entire invasion, then it is always optimal to allow some of the invasion to remain. For an arbitrarily small invasion, if the damages compound indefinitely at the discounted expected intrinsic growth rate are less than the marginal costs of eradicating the invasion then the optimal policy is not to control the invasion at all when it is sufficiently small. This then implies that eventually, eradication is not an optimal strategy for an invasion of any size.

For a controlled biological invasion that is small, the marginal costs of control are balanced against the infinite geometric sum of intrinsic marginal damages. In summing damages, the ratio of successive terms depends on the discounted mean intrinsic rate of expansion of the invasion. If the discounted expected intrinsic growth rate is higher than one, then eradication is optimal for small invasions even if the marginal costs of control are large relative to marginal damages. The reason is that if an invasion is controlled then it is worth eradicating a small invasion to avoid the rapid growth in future costs that accompany a higher expansion rate of the NIS. As an invasion approaches its ecological limit, its marginal growth rate necessarily falls below one. Hence for large invasions, it is the interaction of costs and damages with the discount rate and the invasion growth rate that determines whether eradication is optimal or not. The magnitude of the disturbance that leads to the slowest expansion plays a critical role but not its probability. The combination of control and the inevitability of a sufficient number of bad disturbances eventually leads to eradication.

Trade-Related Studies

It is a generally accepted principle that trade provides a major conduit for the introduction of invasive species. OTA (1993) estimates that 81 percent of invasive weeds have entered the United States via commodity transport. Species 'hitchhike' on commodities, packing materials and transport vessels, especially ships.[2] The World Wildlife Fund (WWF) estimates that as many as 4,000 different species can hitch-hike in typical ships' ballast at any one time (Plant Ark 2004).

Expanding volumes and diversity of trade are seen as having contributed to the growth of invasives in the United States. The expansion of trading partners has served to produce an array of possible invaders. Historically, damage (either actual or anticipated) from the establishment of invasive species has led to import bans or quarantine measures on all commodities from countries known to harbor the NIS (Lynch 2002). These bans and/or quarantine measures designed to protect plants from other plants, weeds, insect and pathogens are called phytosanitary regulations. Because tariff levels in the world have decreased since the first GATT agreement[3], these phytosanitary regulations (also called non tariff or technical barriers to trade) are more likely to be binding. In addition, as countries attempt to protect domestic producers competing with foreign counterparts without the benefit of tariffs, governments may use these types of trade barriers as a non-

[2] More infamous examples of hitchhiking species include the Zebra Mussel (*Dreissena polymorpha*) and the Asian Clam (*Corbicula fluminea*).
[3] The General Agreement on Tariffs and Trade (GATT) was succeeded by the World Trade Organization (WTO) in 1995.

transparent means of protectionism even when little scientific basis for these regulations exist. As a result, measures instituted to protect domestic ecosystems at the expense of trade are coming under increasing scrutiny.

There are two distinct concerns regarding increased globalization and the occurrence of trade with respect to NIS. The first is that increased trade will bring with it a global homogenization that will lead to a decline in diversity. Indeed, Polasky, Costello and McAusland, (2004) argue that trade increases specialization in production which in turn promotes specialization in ecosystems and their associated biodiversity. Trade affects habitat loss through conversion of land for economically driven uses such as agriculture, forestry and expansion of urban areas. When trade partners have similar species, trade has little effect on global biodiversity, but may affect it at the local level. On the other hand, with endemism, specialization can cause significant declines in both local and global biodiversity. This loss in biodiversity may reduce the overall utility gains associated with moves toward free trade.

The second concern about free trade is that increases in standards of living leading to increases in import demand, will increase the probability of NIS (Jenkins 1996). Given that most NIS are brought to their new homes unintentionally in ballast water, packing material and cargo, the resulting invasions represent market failure rooted in international trade (Margolis and Shogren 2004).

Establishing a definitive link between NIS and trade is not easy, stemming mostly from data issues. Estimates of introductions are usually species or region specific, while trade data tend to be reported by commodity or country of origin. Also, there is a difference in time horizon between the two. Trade volumes can be measured monthly, quarterly, or annually while species introduction, and eventual propagation, is measured in terms of weeks, months, years and even decades. Finally, while trade data is provided in a relatively detailed and abundant manner, data on NIS are of notoriously poor quality (see, for example, Nozic et al. 2000 or Pimentel et al. 2000). Thus, there have been few attempts to quantify the link between trade and invasives. The exceptions to this are discussed below.

Dalmazzone (2000) examines whether available data support the contention that economic activities in general, and trade in particular, are correlated with NIS. He tests which activities play a role either as pathways/vectors, or by increasing the domestic economy's susceptibility. The study measures the degree to which various economic factors explain the share of established alien plant species of total native species across 26 countries. For example, of Egypt's 2,015 native plant species, there are 86 invasives, representing a share of 0.043. The first hypothesis Dalmazzone tested is that invasions are an increasing function of the openness of the economy (in terms of movement of goods and services as well as people). He uses trade and tourism as proxies for openness. The second hypothesis is that invasions are an increasing function of the degree to which natural habitat are disturbed in the course of economic activity. For this he uses measures of grazing land and agricultural activity.

The first hypothesis, that of openness, is marginally rejected. Dalmazzone makes this claim by finding that neither trade (as a percentage of GDP) nor tourism are statistically significant in explaining the share of NIS. However, when total trade flows are measured and imports inserted as a separate measure, there is marginal significance. Also, trade duties are significant and negative. This finding, that trade as a percentage of

GDP is not significant but imports and duties are, seems to support the idea that its not so much the volume of trade that is important in determining NIS, but rather what goods are traded and from where. Duties influence the types and source of goods a country receives. Dalmazzone reports evidence supporting the second hypothesis, that is that economic activity increases the probability of NIS. Population is significant and positive, as is per capita GDP. Agriculture is also significant, but has a negative sign. This may be explained by the fact that agriculture involves a simplification of ecosystems and alien plants and insects, along with indigenous populations, are frequently eradicated to support production.

Levine and D'Antonio (2003) attempt to forecast the rate of future invasion by examining the historical relationship of international trade with the level of invasive species in the country. They apply several different species accumulation models, noting that there is no current consensus as to which performs best. Past merchandise trade is related to accumulated number of biological invasions focusing on insects, plant pathogens and mollusks. All three models fit the historical data well.[4] Their predictions for increases in NIS introductions as a result of international trade volumes between 2000 and 2020, range between 3 and 61 percent, depending on the model and the species. Given the evidence and performance of the models, they support the most likely estimate to be between 15 and 24 percent. The paper notes that these values represent less than twice the number of observed invasions over the 20 year period between 1960 and 1980, in which imports were roughly 10 percent of the amount forecasted for the next twenty years. This would imply that while the rate of introductions may slow, the total number

[4] The three models were Log-log species area, Log-linear species area and Michaelis-Menten.

of NIS is likely to increase. Thus, if the 10 percent rule is applied, the burden on society, even looking at the lower bound numbers, is likely to be large.[5]

The problem with using trade volumes in and of themselves as a predictive tool is implied in Dalmazzone's work. He showed that total trade is not a significant predictor of the rate of species invasion, where imports are. Types of goods imported, modes of transportation and the type, and state, of receiving ecosystem are key factors (Colautti et al. 2003). The relationship between NIS and trade is not linear; spatially or temporally.

Studies on Marine Shipping

Accepting there is a link between trade and NIS, what is the most likely vector for their introduction? Those studies that pay passing attention to packing materials, or the commodities themselves, usually do so in the context of explaining how the relevant species arrived in the ecosystem, rather than attempting to establish a firm link between traded items and NIS (OTA 1993, Pimentel et al. 2000, Nozic et al. 2004) Those studies that do look at pathways tend to focus on transoceanic shipping as the most likely vector for invasives, especially aquatics. There are a number of studies which have attempted to measure the degree to which shipping plays a role in both the introduction and spread of NIS.

Predicting invasions in estuaries, seas and lakes utilized by foreign transoceanic ships is difficult because these ecosystems are impacted by many human activities, not just trade. Also, successful invasions may dramatically change the ecosystem, potentially increasing vulnerability. Thus, as stated above, an increase in NIS may have more to do with an increase susceptibility than trade volumes. Invasives may interact and effect

[5] Rule of thumb states that 10 % of the species introduced will become invasive.

distribution or colonization of existing NIS. Finally, in systems subject to multiple mechanisms or introductions, it is difficult to predict the timing or types of species trade is responsible for introducing (Horan and Lupi 2004).

Fernandez (2004) examines under what conditions various invasive species management programs are optimal given that the goal of the regulating port is to minimize social costs of shipping, including any potential environmental impacts. The shipper's objective is to maximize expected profits. The paper shows that, using estimated costs of various management techniques used to control for invasive species (ballast water treatment or exchange and biofouling), ships maximize profits by biofouling alone in the absence of existing subsidies or taxes. This result is important given that most regulation (including IMO standards) focus on ballast water. The potential for cross media multiple externalities adds an index of invasive species damage severity to the mix. Given imperfect information most shippers know they will ultimately bear the cost of only a fraction of any damage they cause. This causes their optimal chose of ballast management and biofouling management to diverge from the socially optimal choice.

Fernandez shows that by applying an incentive mechanism consisting of two subsidies (one based on per unit ballast water and the other a lump sum), and depending on the shipper's anticipated liability share of the damage, a socially optimal mix of ballast management and biofouling management can be achieved. This is done through a lump-sum subsidy that the port pays to ensure the shipper reports its true anticipated damage rate. As the shipper reports larger values of anticipated damage, the two subsidies vary inversely with respect to one another. If the shipper reports small values, that is, if the shipper reports that its liability share for cross media damages will likely be small, then a large per unit ballast water subsidy is chosen by the regulating port. This is because an unregulated shipper would otherwise discount cross media damages and select an inefficiently low level of ballast water abatement and an inefficiently high level of biofouling abatement. As the shipper's reported value increases, the shippers increasing liability for multiples externality damages serves as an increasingly sufficient incentive for it to select the socially optimal combination of ballast and biofouling. As a result, the per unit ballast water subsidy necessary to ensure that the firm selects the socially optimal combination decreases. If the regulator relied on the ballast water subsidy as the sole policy instrument, the shipper would have the incentive to report small values of anticipated damages regardless of the true liability in order to manipulate the regulating port into providing large ballast water subsidies. The regulating port, thus can use the lump sum subsidy to combat the shippers incentive to report false values of anticipated damages.

Colautti et al. (2003) also examine transoceanic shipping as a possible vector for NIS, focusing on the Great Lakes. Given the lakes are a freshwater ecosystems closely association with human activity, they are particularly vulnerable to NIS. There are two ways Great Lakes receive NIS from ballast tanks. The first is through large volumes of water from a small number of ships that enter the region with saline ballast water ("ballast" ships). The second is from large numbers of ships that enter, loaded with cargo, and fill their tanks in lakes as they discharge cargo ("no ballast" vessels). The loaded water mixes with the residual water containing both living organisms and resting stages, in the tanks. As these "no ballast" ships trade around, loading cargo and subsequently discharging ballast, they may facilitate invasion. The paper attempts to determine the relative importance of the two types of introduction.

There is evidence (MacIsaac et al. 2002) that propagule pressure of individual ships that enter the Great Lakes loaded with cargo and that declare no ballast on board, is typically one to two orders of magnitude higher than that of vessels that exchange ballast water. Because no ballast vessels dominate (about 90 percent) the inbound traffic of the Great Lakes, these vessels collectively appear to pose the greatest risk of new introductions, even though their individual risks are lower than ballast ships.

According to Colautti et al (2003) the fraction of inbound "ballast" ships has fallen sharply throughout the 1980s and 1990s and is thought to have leveled off in recent years. Inbound traffic has been dominated by ships from Europe, which account for about 88 percent of the top 10 vessels source region. Thus, many of the NIS in the Great Lakes are from habitats in Europe, notable the Baltic Sea and lower Rhine River areas. The first port of call for most (52 %) of ballast ships is Lake Superior. While the first no ballast vessels ports of call are Lake Ontario (about 40 %) and Lake Erie (about 43 %), the majority of deballasting still takes place in Lake Superior (even when it's the third or fourth stop). Thus, Lake Superior receives more discharges than all other lakes combined.

While Lake Superior gets more ballast water, the lower lakes report more NIS. The paper suggest several reasons why this may be so.

1. Lake Superior is not as supportive of an environment. Smith et al. (1999) show that in the upper Chesapeake Bay, relatively few ballast mediated NIS are found due to adverse environmental conditions.

2. There are NIS, but they remain undetected due to bias and low sample effort (most research is done on the lower lakes).
3. Lake Superior hasn't been altered physically, chemically or biologically to extent of the lower lakes (although some ports are similar in terms of human use and physical-chemical stresses).
4. Ships may not deballast and port as assumed by the model (i.e. en route) so lower lakes are actually getting more than shown.
5. NIS could be hull fouling (hull, anchor chain, etc) and not originating from ballast, although the authors heavily discount this explanation.

The results of the Colautti study imply that policies should have greater emphasis on invasions mediated by resting stages in ships sediment and less on ballast water itself. Resting stages are less likely to be purged during ballast exchange because they reside at the bottom of tanks and are less likely to be killed by saline when tanks are refilled. To date, however, most policies still focus on ballast water exchange. Beginning in 1993, with the implementation of the US Nonindegenous Aquatic Nuisance Prevention and Control Act of 1990, and later by the US National Invasive Species Act of 1996 and the Canadian Shipping Act of 1998, oceanic ballast water exchange (BWE) was mandated and remains the predominate approach to prevention. The BWE legislation implemented in 1993 stipulated that ships must deballast in open water not less than 2K deep and at least 320Km from nearest coast line.

In February 2004, a new international ballast water convention was adopted. This International Convention for the Control and Management of Ships Ballast Water and Sediment will enter into force 12 months after ratification by 30 countries representing 35% of the world's merchandise shipping tonnage. Domestically, the US Coast Guard currently requires all vessels transiting to US waters with ballast water that was taken within 200 nautical miles of any coast after operating beyond the US Exclusive Economic Zone (EEZ) conduct one of the following:

1. Mid-ocean ballast water exchange prior to entering US waters
2. Retain ballast water on board while in US waters, or
3. Use a Coast Guard approved alternative environmental sound to treat the ballast water.

Horan and Lupi (2004) examine the economic efficiency of several compliance strategies in addition to BWE. The paper also argues that there are two features which complicate the traditional process of emission-based approaches (standards or incentives), such as outlined in the Colautti et al. paper. The first is that while not every vessel will actually emit a species, *ex ante* each vessel is a potential emitter and so society should benefit from all vessels undertaking biosecurity actions to reduce the probability of an invasion. Second, biological emissions are highly stochastic and essentially unobservable given current monitoring technologies. So there is no direct way to observe or otherwise indirectly measure if a vessel is responsible for an introduction. This makes enforcement problematic.

Given this, the paper examines the relative efficiency of various economic incentives for reducing risk of NIS invasion in the Great Lakes where the type of incentive differs according to the compliance measure used. Horan and Lupi consider various subsidies to reduce risk of an invasion and implement certain biosecurity measurers. However, the most effective of these subsidies are shown to be excessively complex to administer because they would have to be tailored to individual vessels in accordance with each vessel's marginal environmental impact.

Each vessel entering the Great Lakes is a potential carrier of NIS and makes certain biosecurity decisions based on efforts involved in ballast water exchange, the number and location of stops, time at sea, use of biocides, filtering, heat, etc. The probability of an invasion is decreasing in biosecurity measures and increasing in those measures which made introductions more likely (such as the number of stops). Since damages are presently unknown and perhaps unknowable for many species, a useful method to defining the least cost approach uses probabilistic constraints. The marginal cost of undertaking a particular action equals the imputed marginal value of reduced risk stemming from the action. The marginal value of reduced risk depends on both vessel *i*'s actions and the actions of all other vessels. Four biosecurity techniques are identified and the authors determine which would be most efficient in lowering potential damage due to three possible invaders (Ponto Caspain species, *Corophium spp*. Mysids, and *Clupeonella caspia*). The efficiency of each of the four techniques is then examined under five different management strategies.

The first two management strategies are performance-based approaches while the last three represent flat subsidies. Thus, the first two are administratively more difficult and resource intensive than the last three.

The least cost strategy encourages full participation by all vessels with the aggregate mix of adopted technologies depending on the levels of risk stipulated in the experiment. Ballast water exchange is optimally used more extensively for larger allowable risk levels. As the overall level of risk is reduced, the effort required for an effective ballast transfer becomes so high that it becomes optimal for some vessels to incur fixed costs of filtering to take advantage of its low unit cost and high degree of effectiveness. Heating's high unit costs prevent it from being a preferred option by any vessel for any risk level. The cost of the risk reduction strategy depends on the overall level of risk assumed. At relatively less stringent levels, the control costs are 28 percent larger than in the least cost allocation system. At lower levels of acceptable risk, the cost differential falls to less than 10 percent. The model shows that all vessels are willing to participate in this scenario as well.

Studies on policy responses

If subsidies can be used to effectively manage threats by individual shippers, what policy options are available at a more aggregate level? That is, is there an effective way to manage general trade flows so as to reduce the risk of invasives entering the country? Quarantine and import bans have been the often favored methods over the years (Jenkins 1996). However, one must consider the cost of these restrictions , including the loss in consumer surplus. There are several studies which look at optimal policy responses to trade in light of these factors.

The primary conduit of unintentional introduction of NIS is through agricultural products, timbers, packing materials, ballast water and tourism.. However, the relationship between protectionism and the effort to slow invasives by slowing trade is not simple. Freer trade, by way of reduced protectionism may even lead to less damage for some countries because while a decrease in protectionism increases trade volume and the platform for NIS, it also changes the product mix of a country and thus alters susceptibility (Costello and McAusland 2004).

In a series of papers, Costello and McAusland, (2003, 2004, and with Polasky 2004) examine specific rules for trade and invasives, given expected damage, rate of infection in imports, and changing production costs of foreign suppliers. Most estimates of NIS costs are derived from crop damage. Agriculture related costs make up 90-93 % NIS damage of the OTA (1993) estimates and more than half of Pimentel's (2000) numbers. None of these consider ecosystems damages however.

The first paper (Costello and McAusland 2003) argues that there may be an upper bound on the marginal costs associated with invasives with respect to agricultural activity. This is especially true because costs incurred in the absence of viable populations of non native species are not deducted. For example, $27 billion of the Pimentel estimate comes from damages and control costs associated with non native crop weeds. Since it is plausible native species would either become or expand their presence as weeds in the absence of nonnative species, this figure overestimates the true marginal costs of NIS in this context. The article serves as a "first pass"' at establishing a theoretical relationship between invasive-related damage and patterns of trade and protectionism. The frequency and severity of damage are related to the extent to which the host country modifies its natural environment and the frequency of exposure. The frequency of exposure is proxied by volume of imports. The paper explores the relationship between trade, protection and NIS within an agricultural framework.

Assume a two country, two goods model where each country either exports agricultural goods and imports manufactured goods, or vise versa.[6] The paper defines the relationship between tariff levels and expected damage from an invasion. It relates the change in expected damage of type *k* to changes in tariff rates of a series of sensitivity, or elasticity, measures. These include the elasticity of the arrival rate with respect to the volume of imports and the elasticity of supply for agricultural goods with respect to its domestic relative price (both of which are shown to be positive). This implies that the arrival rate of NIS increases with the volume of imports and this has a positive influence on the rate of change in damages.

The authors then show that the effect of protectionism depends on how responsive imports are to domestic prices of agriculture goods and thus how import tariff affects relative price. An increase in the tariff on imports reduces the volume of trade and so long as trade is a conduit of introductions, the expected arrival rate of a new NIS will also fall. However, this policy will have a distortionary effect on domestic prices, which effects the production mix in an economy. If the import tariff causes domestic agriculture prices to rise, this may stimulate domestic production affecting the extent to which the country is susceptible to damage.

[6] Assuming constant returns to scale and competitive markets.

The fact that an import tariff may raise the expected damage a rising from invasive species comes from the fact that augmented damages depend in part on the sensitivity of those types of damages to agricultural output. It also depends on the elasticity of the introduction rate with respect to the volume of imports. The assumption made in the paper is that the latter term equals 1 and derives from the simple fact that while contamination rates of traded goods appear to vary with the country of origin and by the mode of transport, these characteristics are unaffected by a uniform barrier to trade such as a tariff. Moreover, there is no evidence that the rate of hitchhiking is anything but proportional to the volume of a given commodity traded, for a given trade partner. However, to the extent that changing tariffs change a country's mix of partners and/or commodities, this assumption may not hold.

Overall there is a general prediction that barriers to trade are more likely to backfire as a means of preventing damage from exotic species when the country in question is an importer of agricultural goods, when the country's citizens are in a high income group and so demand for agriculture goods is price insensitive and when there is substantial potential for domestic agriculture to expand in response to high local prices.

The paper focuses on agriculture using crop damage as a proxy for total damage. Estimates of invasion-related damage that are based on one type of damage may be misleading however, particularly if we believe pecuniary losses to agricultural production are more easily observed than ecological damage from NIS. Most real world estimates of invasion related damage derive predominately from estimates of damage to crops and livestock. Only a small amount of funds in the US are spent on non-crop related measures (GAO 2001). Also, policy changes that lead to reduced crop damages (i.e.

reduced protectionism) may simultaneously increase ecological damages. If we treat damages arising in agriculture as a proxy for overall costs related to invasives we may misjudge not only the magnitude of these costs but other qualitative effect that trade policy has on the problem. No averting behavior is considered in their model. They assume that industrial mix respond to producer prices but not net harvest rates. In an economy in which producers face undistorted (i.e. world) prices such behavior (e.g. switching from corn to wheat) may reduce the magnitude, but not change the sign, of crop damage imposed. However, if producers initially faced distorted prices than biological invasions may actually generate net benefits by getting farmers out of subsidizing behavior which may have ecological benefits (such as irrigating). The study also does not consider eradication, control or monitoring behavior.

The second paper (McAusland and Costello, 2004) examines substitutability and complementarities between two different policy tools aimed at minimizing introductions. The two policies are tariffs and inspections. The first best strategy would seem to support adopting an optimal Pigouvain tariff which would internalize the externality caused by trade. However, since trade itself is not the problem there is also an argument that it should not be suppressed, rather inspections should be designed to optimally weed out some most offensive individuals. The paper develops a series of optimal strategies depending on infection rates of imports, anticipated marginal damages from infected but undetected imports, and consumer surplus. The importing country's incentive to undertake port inspections is to minimize the costs associated with trade in infected goods, by balancing the costs of additional inspections and more rejections of incoming goods, with benefits of fewer infected units making it past inspectors.

Optimal tariff and inspection mix with respect to infection rates

As a starting point, if the fraction of contaminated goods is sufficiently high, or production costs are high, or marginal damage is low, then it is preferable to simply accept all goods received uninspected and charge a tariff equal to anticipated damages based on expected infection rates. However, as infection rates rise, then a given level of inspections is more productive (i.e. detected cases). As more infected units are detected, more are subsequently barred which reduces imported quantities. This, in turn, raises the price of imports, and thus the opportunity cost of rejecting a unit. As long as infection rates are low to begin with, then the rate at which prices respond to inspections is low and more inspections increase welfare. When infection rates are higher to begin with, the rate at which prices respond increase and there is a higher opportunity cost. At this point an increase in inspections decreases welfare.

The home's optimal tariff also increases with infection rate, but absolutely so that the higher the infection rate, the more inspections are redundant. When initially detected infected units is low, but the actual infection rate is high, inspections should increase, increasing in the cost-recovery portion of the tariff. But even as more inspections lead to increased opportunity costs, the higher infection rates imply an increase in expected damages, thus higher tariff rates needed to cover the cost of the damage.[7]

Optimal tariff and inspection mix with respect to anticipated damage

[7] However, increasing inspections could actually decrease the probability of undetected NIS getting in the country so the tariff needed to cover the anticipated damages may actually decline. Therefore, the paper states that tariffs *tend* to increase with infection rates.

An increase in the marginal damage from infected imports unambiguously requires greater inspections but because stricter monitoring reduces the proportion of units that will be accepted to begin with, the optimal trade tax may instead become smaller. That is, an importer may want to treat goods harboring more dangerous contaminants with harsher inspections but smaller trade tariffs. So the importer's policy mix should be based on the level of infection rates as well as anticipated damage for undetected infected goods. If anticipated damage is high, more inspections are needed, but the good should be subjected to lower tariffs. If infection rates are high, the more efficient strategy is to rely on tariffs and less on inspections.

The paper goes in to discuss how the policy mix is affected with a change in production cost in a foreign country and with multiple trading partners. Rising foreign costs lowers exports and imports and raises the consumer surplus for the last good accepted, making rejecting units less attractive at the margin. With many trading partners, the importer wants to set policy so as to maximize trade with the most efficient partner (in terms of some combination of production costs, infection rates and damage), it is more effective to do so through tariff policy than inspections. However, this may be difficult given international trading rules. Domestic policy formation must take place within the larger framework of regional and global trade policy.

Policy in an international context

As stated above, the rules for international trade that allow countries to implement regulation to protect human and plant life (sanitary and phytosanitary rules especiallymay also be used as disguised protectionism. Indeed, once rules are established, it becomes difficult to objectively distinguish genuine attempts to protect home country ecosystems and attempts to protect home country producers. Margolis and Shogren (2004) apply Grossman and Helpman's model of political economy in tariff formation in the presence of interest groups, and add externalities in trade. Thus, the government's objective function now incorporates a damage term from potential NIS. By incorporating the invasive species externality of trade into the predominate model of the political economic of tariff formation, the paper shows that countries, freely setting tariffs, will add this the external damage to the tariff chosen.

Grossman and Helpman's model illustrates the gap between equilibrium and optimum policy when political contributions are introduced to the government objective function. In this context, the gap is a logical measure for disguised protectionism. The most important feature of the model is that the two components of the tariff - disguise protectionism and internalization of invasive damage – cannot be distinguished without knowledge of either the social damage vector or the weight the government places on public welfare, neither of which are directly observable. In this context there is no way to design trade rules that will reduce disguised protectionism without nations giving international bodies the right to decide how much value to place on public goods endangered by NIS. As with other such issues (e.g. GMOs) it is likely individual countries will be resistant to allowing domestic NIS policy be determined by international bodies such as the WTO.

Margolis and Shogren conclude by observing that public polices to control NIS are not immune from political pressures. They find that private political contributions cause the regulators to select a tariff level that exceeds socially optimal levels. Free trade is also constrained with the invasive species tariff being set higher than it would be if the government were not influenced by rent seeking contributors. This gap is disguised protectionism created by the existence of the externality, NIS. Good intentions aimed at reducing risks to native ecosystems from NIS can thus be leveraged into protectionists policies.

As shown by the review thus far, there have been two broad policy approaches to control NIS: one focusing on vector (usually shipping) and the other on limiting the amount of imports entering the country either by quarantine bans or tariffs, or by customs or port inspections.

The US is bound by two major trade regimes: NAFTA and WTO. The WTO's legal framework imposes the principle of national treatment which requires importing countries treat foreign goods the same way they treat "like" domestic goods (Article III). There are general exceptions to this which include measures "necessary to protect human, animal or plant life or health" (XXb) and those "relating to conversion of exhaustible resources" (XXg).[8] Disputes arising over the meaning of these two passages led to two agreements: SPS (Sanitary Phytosanitary), dealing specifically with issues of human, animal and plant health; and TBT (technical barriers to trade), dealing with coordination of product regulations and setting criteria for imposing potentially discriminatory technical standard on imports. SPS standards are based on risk assessment. Within this context, "zero" risk has been accepted as a reasonable goal for a country to pursue. The agreements encourage full disclosure of scientific information and symmetry of information among members. For TBT the idea is for standards to be made in terms of

[8] See http://www.wto.org/english/thewto_e/whatis_e/whatis_e.htm for a complete discussion of the trading rules and processes under the WTO framework.

product specifications or characteristics that can be measured at the border, not in production or process standards. There is no equivalent requirement for scientific assessment in TBT issues.

The risk assessment process under SPS standards is not inconsequential and the cost of conducting such analysis can be prohibitive. For example, a dispute surrounding the import of raw Siberian larch (timber) called for a risk assessment that cost in excess of $500,000 (Jenkins, 1996). If international trade authorities set standards to determine how invasive species risks should be measured or assessed, then trade regulation decision based on these standards could have the potential to overrule tougher national, state or local regulations (Jenkins, 1996 and OTA, 1993). The results could lead to weaker overall standards and greater threats of biodiversity loss. Exporting countries with little or no NIS standards could resist the more onerous standards imposed by strict importing countries. Thus, increasing border protection measures imposed domestically have the potential to be challenged in the WTO framework. There are provisions within the WTO framework that allow countries to uphold tougher domestic standards, as long as they are not in conflict with agreed-to WTO rules.

As compared with the WTO, NAFTA allows national governments more latitude over their technical standards and SPS measures which could impact policy surrounding invasive species. The first burden of proof is assigned to the plaintiff or party challenging the protection measure. Arbitration cases may be heard by either a NAFTA or a WTO committee at the option of the defending party. NAFTA also established the North American Commission for Environmental Cooperation (CEC). The CEC strengthens regulators under NAFTA in two ways. First, it explicitly states that an SPS measure does not have to be the least trade restrictive option to be considered "necessary" to achieve its goal. Second, the scientific basis for setting levels of allowable risk in SPS measures is determined by the regulating authority (the defendant) not by a dispute settlement panel.

A recent study by the CEC (Perrault et al. 2003) showed the NIS impacts from regional trade primarily exacerbates impacts of global trade. It determined that trade among NAFTA countries spreads invasive species that have been introduced as a result of trade of NAFTA countries with non-NAFTA countries. Many fewer examples exist of regional trade facilitating introduction and establishment of an invasive species within NAFTA countries. The study also purports that since NAFTA, regional and global trade have grown significantly while the capacity to inspect for NIS has remained constant.[9] As a result, the potential for introduction of NIS via trade has increased significantly.

The report recommends, in addition to existing effort to exchange information and ideas, that NAFTA countries:

1. develop a North America strategy to address NIS concerns including building technical and institutional capacities;
2. recognize costs associated with introductions via trade of NIS and shift focus from increasing trade while dealing with NIS to addressing NIS while allowing trade;
3. minimize dependence on inspections by, for example, ensuring that those responsible for the movement of NIS are motivated to reduce risks they pose of introduction of NIS;

[9] Approximately 2 percent of goods are inspected. Thus, if the volume over which this percentage is applied is increasing, the total number of introductions may be increasing as well.

4. institute additional measures to prevent introduction and establishment of NIS including, for example, requiring documentation of country or origin of specific materials, mandating use of materials other than SWPM (solid wood packing material), etc;
5. encourage involvement of regional organizations in development of regional and international standards; and
6. ensure that existing and future bilateral and regional FTAs provide sufficient leeway to develop sanitary, phytosanitary and zoosanitary measures necessary to prevent the introduction of NIS, including through the use of a pathway approach (Perrault et al. 2003).

More research is needed to establish a definitive link between NIS and trade. It is likely that it is not the sheer volumes of trade that account for increases in NIS, but rather such things as the region or origin, packing material and the effectiveness of monitoring and preventative efforts. "Real world" policy for controlling damage seems to be more reactive than proactive, suggesting higher initial populations should lead to increases in the restricted policies. Economic intuition states that higher initial populations should lead to lower marginal damage and call for less restrictive policies.

Empirical Cost and Benefits Estimates by Species

This section is organized by types of species and for specific species within those groupings. The groups are fish, crustaceans, mollusks, and aquatic/riparian plants.

Fish

Pimentel et al. (2001) report that a total of 138 non-native fish species have been introduced into the United States, most taking place in states with warm climates such as Florida and California. They also state that 44 native species are endangered due to NIS with an additional 27 being negatively affected. The paper estimates that economic losses due to alien fish is approximately US$1 billion annually. This takes into account the estimated annual US$69 billion in benefits from sport fishing.

Sea Lamprey

The Sea Lamprey has caused great losses to the commercial and recreational fisheries of the Great Lakes as a parasite on native fish. Unlike many other Great Lakes invasives, it entered the Lakes naturally traveling from its natural range in the Atlantic through the St. Lawrence Seaway (Jenkins 2001). Control methods for lampreys include lampricide for larvae control, barriers, traps, and a sterile male release program (Great Lakes Fishery Comm. 2004). A number of estimates are available for the costs of lamprey control and prevention. The OTA report states that $10 million is spent annually for control and research and another $10 million on fish stocking. Another estimate gives total control costs for annual control and monitoring of sea lamprey in the U.S. and Canada as $13 million (U.S. Invasives Species Council; Jenkins 2001). The U.S. GAO, based on a survey of seven states, estimated that 1999 expenditures on sea lamprey were $275,000 for New York and $3 million for Michigan (GAO 2000). Lupi et al. (1999) report that Granular Bayer treatment, a lampricide, costs approximately $5 million per application in U.S. waters of Lake Huron. This same treatment in the St. Mary's River costs $4.2 million per application (Lupi et al. 2003). The costs for sterile male release are on the order of $300,000 per year in Lake Huron (Lupi et al. 1999; Jenkins, 2001).

Lupi et al. (2003) estimate the benefits of lamprey control on the St. Mary's River to Michigan anglers. Three options are evaluated, sterile male release and trapping, sterile male release/trapping with larvicide applied every five years, and sterile male release with a one time application of larvicide. An existing random utility model of recreational fishing for Michigan anglers for Michigan waters of the Great Lakes was adapted to estimate economic benefits of increases in Lake Huron lake trout populations as a result of lamprey control. (Lampreys that spawn in the St Mary's River are the source of lampreys in Lake Huron.) Treatment options were linked to changes in lamprey populations and then to changes in trout populations. The authors assumed a proportional change in catch rates to changes in trout populations. These catch rates were then fed into the economic model to determine changes in recreational fishing trips and thus the benefits of control. Benefits were measured in the year 2015, after allowing populations to adapt, and in 1994 dollars. Option 1 had $2.6 million annual benefits, option 2, $4.7 million, and option 3 $3.33 million.

The authors also calculated the net present value of net benefits (benefits minus the treatment costs) for a range of interest rates. They found that the estimated net present values were similar across all three options, even though annual undiscounted benefits varied by option. The difference appears to be the cost and the timing of controls and trout population growth. The option that had the highest net present value varied by which discount rate was used. Nevertheless, across all options, net present values were positive for a wide range of interest rates and suggest that there are definite economic benefits for control. Considering that only benefits to anglers were measured, there are likely to be more economic benefits than those measured. Benefits arising from other uses and non-uses that would further increase net present benefits of control.

Two other sources report on the benefits of control. The Great Lakes Fishery Commission reports benefits in the range of $2-4 billion per year (Sturtevant and Cangelosi 2000). Lost fishing opportunities and indirect economic impacts if control were terminated are estimated at $500 million annually (OTA 1993).

Ruffe

The Ruffe is another invasive fish, native to Europe, that like the lamprey has invaded the Great Lakes. It is a predator on native fish and competes for habitat. Control includes toxins, trawling, and ballast water management. Estimated losses for the native fishery are estimated at $0.5 million annually (Jenkins 2001). For Lake Erie, between 1985 and 1995, Hushak (1997) estimated losses of $600 million for the sport fishery.

Leigh (1988) evaluated the benefits and cost of a proposed Ruffe control program. The proposed program would control Ruffe using a pesticide also used on Sea Lampreys and would be used at river mouths at specific times of the year when Ruffe are concentrating in those locations. Control would occur over an 11 year period, at which time the population would be no longer a significant threat. Total costs for the control program would be $12 million with about 10%-20% variability depending on water level fluctuations in the rivers. The benefits of control are estimated based on the value of both commercial and sport fishery impacts over a 50 year time period. Without the control program, Ruffe populations are estimated to expand to all Great Lakes and to cause declines in walleye, yellow perch and whitefish. Angler day values (1985) for Great Lake sportfishing were used as the basis of benefits for sport fishing and broken out between values for walleye and perch and all other fish except salmonoids. It was assumed that decreases in native fish populations would lead to proportional decreases in the number of angler days per year. Three scenarios were estimated, a minimum, moderate and maximum for fish population reductions. If fish populations occur right away, then annual benefits of the control program for both sport and commercial fishing varied between $24 and $214 million for the three estimates. Assuming that benefits accrue over the 50 year time period, and discounting benefits, the net present value varies between $105 million and $931 million. An estimated net public savings of $513 million could be achieved for the moderate scenario, primarily benefiting recreational fisheries.

Other Species

Other invasive fish include the Round Goby, which inhabits the Great Lakes and is a predator of benthic fauna. Currently there are no established controls for the goby but research is underway (Jenkins 2001). The mosquito fish has caused the declines of at least 15 native species in Southwestern desert rivers and springs (OTA 1993). The grass carp and common carp that were introduced to control aquatic weeds, have become a problem as they indiscriminately consume aquatic vegetation and destroy habitat for young native fish. (OTA 1993). There are no known specific economic studies available for these species.

Crustaceans

Invasive crustaceans include the European Green Crab, the Mitten Crab, the opossum shrimp, and some species of crayfish. Estimates of costs attributed to the Green Crab are $44 million but it is unclear what those costs include (Licking 1999).

Mollusks

Pimentel et al. (2001) report that 88 species of mollusk have become established in the US. However, this number is based on the OTA study which is over 10 years old.

Zebra Mussels

Zebra Mussels are one of the best studied and well-known aquatic invasive species. Originating from the Caspian Sea, they are assumed to have been introduced first to the Great Lakes via ballast water discharges. Now found throughout the Great Lakes and rivers of many states and Canadian provinces, Zebra Mussels colonize docks, locks, ship hulls, water intake pipes, and other mollusks and cause great damage to power plants and water treatment facilities. Controls include biocides, chlorine, thermal treatment and mechanical/manual removal (Jenkins 2001).

There are many estimated costs for preventing, controlling, and studying Zebra Mussels. Unfortunately, the many estimates are not always reported in the same units which makes it somewhat hard for comparison. A number of reports and publications have reported that the costs of the mussel to be around $5 billion. A US Fish and Wildlife estimate as repoted in Sun (1994) states that for a 10 year period (1990-2000) the costs in the Great Lakes will be in this range. This same estimate appears at least 4 other times and is presumed to be restatements of this original estimate (Anonymous, 1999; Jenkins 2001; Pimental et al. 1999; IMO 2001). However, another US FWS estimate puts the cost of damages over 10 years to intake pipes, water filtration equipment, and power plants at 3.1 billion (Cataldo 2001).

Many of the cost estimates deal with the impacts on power plants and water treatment plants. OTA reports that the New York Seas Grant Extension Service estimated the costs of the Zebra Mussel to the power industry alone, were as much as $800 million for plant redesign, and a further $60 million annually for maintenance. In addition, fouling by Zebra Mussels of cooling or other critical water systems in power plants can require shut down, costing as much as $5,000 per hour for a 200-megawatt system[10] (OTA 1993). Armour et al. state that the net impact on the US Great Lakes power plants (46) could be $100 million annually based on a one to two day downtime and a 1% reduction in plant heat rate. USGS estimates that annual control costs for hydroelectric plants are $83,000 per plant, for fossil-fuel plants $145,000, and $822,000 for nuclear plants (Anonymous 1999). One major power utility reported costs for 1991 of mussel monitoring at $100/megawatt of generating capacity (Jenkins 2001). O'Neil (1997) reports on a 1995 study of 35 states and 3 Canadian provinces that found the economic impact of Zebra Mussels to have total costs of $69 million, with a mean of $205,570 per facility (339 facilities surveyed). Nuclear power plants had the highest expenditure of $787,000 per facility, whereas fossil fuel electric generating stations had

[10] Some invasive species (such as the Zebramuscle) have also provided benefits to the habitats they 'invade'. Most cost estimates of invasive species fail to take benefits into account, thus leaving them open to criticisms of overstating costs. At the same time, most studies fail to account for eco-system damage,

the lowest expenditure of $146,000 per facility. Annual expenditures were found to have increased between 1989 and 1995, from $234,000 to $17.8 million as the range of the mussels increased (O'Neill 1997).

Upgrading chlorination injection for water utilities in six locations around the Great Lakes could cost between $250,000 to $2.5 million per location (Armour et al. 1993). Water power plants are reported to spend around $3 billion annually (Licking 1999). Research expenditures from 1992-1994 were $8.8 million annually (Hushak and Deng 1997). Reutter (1997) reports that the average large water user in the Great Lakes spends $350,000-$400,000 on Zebra Mussel control. Sturtevant and Canelosi (2000) cite the same figures, but clarify that these amounts are per year and just for cleaning water intake pipes.

For Great Lakes water users with lake water intake structures, Park and Husak (1999) report on the results of a 1994-95 survey of 418 facilities using surface water consisting of industries (44%), municipal water plants (28%), private utilities (15%), and public utilities (14%).[11] Average monitoring and control costs from 1989-1994 were $0.43 million for 142 reporting facilities. Control costs were the sum of costs for retrofitting, physical removal, mechanical exclusion, chemical treatment and other related costs. Monitoring costs included labor, equipment investment, training, and contracts for monitoring. Using this figure and extrapolating to all facilities in the Great Lakes area, total monitoring and control costs were $120 million from 1989-1994, and averaged $30 million annually from 1992-1994. Control costs are further broken out by municipal

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which implies an understatement of costs. The net effect of these oversights is essentially an empirical question.

water treatment plants and for utilities and industries combined. Yearly average costs are given for different size plants from 1989-1994. For municipal water treatment plants, average total costs were $154,000 in 1993 for medium sized plants (11-300 mgd) and $84,000 for small plants (0-10 mgd). Most of this total cost was spent on treatment costs, rather than monitoring. Retrofit costs averaged about 90% of total control costs, and chemical costs were less than 10% of total control costs. Monitoring costs averaged about $5,000 per year for medium facilities and $3,000 for small facilities. For utilities and industrial sources combined, average monitoring and control costs were $439,000 for large, $92,000 for medium and $10,000 for small facilities in 1993. Large facilities were defined as 300 or more mgd, medium was between 11-300 mgd, and small was less than 11 mgd.

A few studies related to the impact on recreational activites have been done. Vilaplana and Hushak (1994) conducted a survey of Ohio residents to determine the effect of Zebra Mussels on recreational activities at Lake Erie. The survey was conducted in 1991 and 439 surveys were obtained. Respondents were questioned about their knowledge of the Zebra Mussel and its impact on their recreation decisions. Thirteen out of 285 respondents who those answering that question actually decreased their time spent recreating at the lake due to the mussel. Boat owners reported expenses for protective paints (average cost was $94), additional maintenance ($171) and insurance costs ($207) related to the mussel, but the sample size was small (14/13%). At the time this paper was written, further work was expected and needed to estimate actual monetary impacts on recreation.

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[11] This paper is one of a number reporting on the results of this survey, conducted by the Ohio Sea Grant and Ohio State University. We limit our discussion here to the latest paper on the survey. See the

Sun (1994) conducted a similar study of Zebra Mussels on Lake Erie recreation. A travel cost model was estimated for Lorain County Ohio boaters (n=140). The results were presented at the Fourth International Zebra Mussel Conference in 1994, and appear preliminary. They are also contradictory, in that both positive and negative impacts of the mussel on recreation seem to have occurred. Although the ideas and generic modeling framework do appear applicable to estimating the impacts of Zebra Mussels on recreation in Lake Erie, this particular discussion did not provide enough details to determine actual impacts.

Other mollusks

Another invasive mollusks include the Asian Clam which by one estimate, cost $4.5 million in compliance in 1980 for the nuclear electric industry, and $1 billion annually in the early 1980's in terms of total losses (OTA 1993).

Cost-effective control strategies for Oyster drills were investigated by Buhle et al. (2004). Oyster drills are marine snails that drill through the shells of oysters in order to prey on them. They have been accidentally introduced into many areas via aquaculture. The paper shows how biological and economic data can be combined to determine the least cost strategy for control at various life stages of the invasive species. Using population data on different life stages can identify which life stage is least costly to control. Oyster drills can be controlled either by the destruction of eggs or the collection of adults. Simulations with different cost parameters showed that targeting of adults was more cost effective than collecting eggs. In general, species that are short lived with high reproductive rates are more effectively controlled by reducing eggs and juveniles, but

references for earlier reports on this same survey.

when adults are long-lived and there is low reproduction, it is more cost effective to target adults.

Plants

Aquatic or riparian invasive plant species include Hydrilla, European Loosestrife, Eurasian water milfoil, melaluca, and salt cedar. Hydrilla blocks irrigation canals, enhances sedimentation in flood control reservoirs, interferes with water supplies, impedes navigation and reduces the productivity of native fisheries. Similar impacts occur from water milfoil. (Jenkins 2001). Florida spends approximately $14.5 million each year on hydrilla control (OTA 1993). European loosestrife invades wetlands and endangers native plants and wildlife by changing the resident plant community and altering the structure and function of the wetland (Jenkins 2001). It is estimated that European loosestrife imposes $45 million a year in control costs and forage losses (Pimentel et al. 2000).

Rockwell (2003) summarized the literature on the economic impact of aquatic invasive weeds. Invasive aquatic plants create a wide impact including those on commercial and recreational fishing, boating, swimming, water quality, navigation, and ecological resources such as wildlife habitat. There is a wide variety in both the types of water bodies impacted, the life cycles and characteristics of the plants, and the means of control. Control may be mechanical, biological, or chemical. Early estimates of the costs and benefits of weed control in Florida were made in the late 1960's. Costs of $6 million were reported annually and benefits were reported as $82 million, with the largest benefits coming from increased land use (due to drainage) and prevented flood damages.

In 1989, Florida spent $14 million on aquatic weed control. Relatively few estimates of the harm done by aquatic weeds or the benefits of control are available from the literature. What is available is concentrated on the state of Florida. A 1991 study found annual benefits of $7.3 million for residential damage control for 11 Florida counties. Benefits of control to improve drainage for citrus production were found to be $5000 per acre or $8000 per acre wit slightly more increases in control by a 1992 study. For vegetable production, benefits were on the order of $300,000 (1993 study).

Recreational benefits are the primary form of benefits estimated for weed control. Three types of benefits have been reported by 5 separate recreational studies. Locations studied were Illinois, Florida, Alabama, and British Columbia. Annual willingness to pay results ranged from $176,000 (1989 study) to $1.3 million (1984 study) (undiscounted figures). Economic impacts and expenditures on recreation were also measured. Impacts were reported by one study on the order of $10 million, and expenditures ranged from $900,000 (1986) to $100 million (1995). Rockwell uses benefit cost ratios from the literature together with the estimated cost of $14 million for Florida weed control on 85,000 acres to generate national estimates of the total impact of aquatic weeds (based on assumptions about Florida as a percent of the national problem). He finds that the range of national impacts are between $1 and $10 billion dollars. A second estimate uses data on the costs of chemicals used to treat weeds. A 1983 study estimated benefits of one chemical (silvex) to be $40 million on 60,000 acres at a cost of $4.8 million, or $80 per acre. Rockwell uses data from two other studies to estimate a cost of $17 million for the entire U.S for applications of the weed control chemical 2,4-D on 223,000 acres.

Conclusion

This paper reviews the economic literature on invasive species, focusing on estimates of the costs of aquatic invasives. The most obvious point of the paper is that the literature is still in its infancy. There are few theoretical, and even fewer empirical, studies dealing with the economic costs of invasive species. The aquatic studies obtaining cost estimates reviewed above show values ranging from several hundreds of thousands of dollars a year to tens of millions of dollars a year. It seems apparent that a systematic approach is needed to develop a consistent method to estimate such costs.

The second point the paper illustrates is the difficulty involved in obtaining such an estimate. Determining economic costs of environmental concerns is no easy task under the best of circumstances. Human health values, use values, existence values, valuations of ecosystem services are all issues environmental economists struggle with every day. The unique circumstances surrounding invasive species add a level of complexity to the task that increases difficulties involved in such valuations at a geometric rate.

Besides the common measurement problems and lack of observable data, measuring the economic costs of invasive species involve determining rates of biological propagation which don’t always conform neatly with economic metrics (such as years or states). There are also the difficulties associated with assessing the risks of invasives. While few NIS actually become invasives and even fewer of those invasives cause significant harm, the harm caused by these few can be quite substantial. How to estimate the benefits associated with controlling such a process is a difficult task.

These issues combine to make policy options difficult to both formulate and evaluate, especially *a priori.* As the literature points out, invasive species and their control have definite public good aspects and thus call for some level of government intervention. However, to what extent and what form that intervention takes place depends on myriad of issues associated with both the region and the species involved. Optimal policy appears to be as unique as the individual species or ecosystem it is attempting to control and protect.

Table 1. Summary of studies providing empirical cost estimates

Authors	Time period covered	Species	Geographic area	Dollar Value	Outcomes
General Estimates					
Pimentel et al	1993-2001	Weeds, vertebrate, insects& mites, plant pathogens,, mammals, bids, amphibians, reptiles, fish, mollusks, arthropods, human diseases.	US, UK, India, Australia, South Africa, & Brazil	$314 billion annually for six nations; $136 billion for the US.	Review of selected literature citing studies which estimate economic losses across six nations, including the US.
OTA	1906-1991	79 harmful invasives Including Sea lamprey, zebra mussel, Asian clam, Salt Cedar, Purple Loosestrife, Melalluca and Hydrilla.	US	Total cumulative damage (1991$) between $97 – 137billion; 3 harmful fish $467million; for 3 aquatic invert.$1.2 billion; and $100 million/annually for control of aquatic plants	Attempts to capture both economic and ecological damages caused, estimating 59% of no indigenous species have caused harm.
Perrault et al		Saltcedar or tamarisk	US	Irrigation value of water loss $39 to $121million/yr	Looks at the effect of invasives on agriculture and trade within the context of the NAFTA agreement. The focus of the study is on recommending strategies including minimizing dependence on inspections by putting more of the burden on potential carriers.

Authors	Time period covered	Species	Geographic area	Dollar Value	Outcomes
Fernandez		Ballast Water		Optimal abatement strategies are adopted applying subsides of 0.5 to 30 cents per cubic meter and a lump sum fee of 0.10 to 0.18 cents	Examines different incentive mechanisms that can be applied to ships to help ports about unintended consequences of NIS.
Species Estimates					
Jenkins		Sea lamprey	US and Canada	$13 million	
GAO	1999	Sea lamprey	New York and Michigan	$275,000 (NY) $3 million (Michigan)	
Lupi et al (1999)		Sea lamprey	Lake Huron	$5 million per treatment	Granular Bayer treatment, a lampricide.
Lupi (2003)		Sea lamprey	St Mary's River	$4.2 million per treatment	Granular Bayer treatment, a lampricide
Lupi et al (1999) and Jenkins		Sea lamprey	Lake Huron	$300,000 per year	Both report this number as the cost of sterile male release
Lupi (2003)	Projected 2015 population and 1994$	Sea lamprey	St Mary's River	$2.6-$4.7 million	Estimates of the benefits of control to Michigan anglers, based on catch rates under 3 different control options. Using present values, all options provided positive net present values.
Sturtevant and Cangelosi		Sea lamprey	Great Lakes	$2-4 billion/year	Benefits of control programs
OTA		Sea lamprey		$500 million annually	Lost fishing opportunities and indirect economic impacts of terminating control.
Jenkins		Ruffe	Great Lakes	$0.5 million annually	Losses for native fisheries

Authors	Time period covered	Species	Geographic area	Dollar Value	Outcomes
Hushak	1985-1995	Ruffe	Lake Erie	$600 million	Estimated losses to sport fishery.
Leigh		Ruffe		$12 million	Estimated total cost of control program. that would run over 11 years
Leigh		Ruffe		$513 million	The same study estimated the benefits of these control programs, both sport and commercial fishing. Estimates of the net present value of the control programs ranged from $105 to $931 million.
Licking		Green Crab		$44 million	Not clear what these costs included.
Various		Zebra mussel		$5 billion	There are many studies which have attempted to estimate the costs of the zebra mussel. This is a commonly quoted figure.
Sun	1990-2000	Zebra mussel	Great Lakes	$5 billion	Sun reports the results of a US Fish and Wildlife estimate.
Cataldo	10 year	Zebra mussel	Great Lakes	$3.1 billion	
Armour et al		Zebra mussel	Great Lakes	$100 million annually	Costs to approximately 46 power plants
USGS		Zebra mussel	Great Lakes	$83,000/per plant/yr (hydroelectric plants) $145,000/per plant/yr (fossil-fuel plants) $822,000/per plant/yr (nuclear plants)	

Authors	Time period covered	Species	Geographic area	Dollar Value	Outcomes
O'Neill	1995	Zebra mussel	35 US States and 3 Canadian provinces	$69 million and a mean of $205,570 per facility	Looked at 339 facilities and measured the economic impact.
O'Neill	1989-1995	Zebra mussel		$17.6 million annually	Estimated that the annual costs increased from $234,000 to $17.8 million
Licking		Zebra mussel	Great Lakes	$3 billion annually	Estimated expenditures by water power plants.
Hushak and Deng	1992-1994	Zebra mussel		$8.8 million annually	Research expenditures
Ruetter		Zebra mussel	Great Lakes	$350,000-$400,000 annually	Estimated control costs of average large water user. Another study stated same figures but for cleaning water intake pipes only.
Park and Husak	1989-1994	Zebra mussel	Great Lakes	$120 million total for period or $30 million annually between 1992 and 1994	This was based on $0.43 million average costs per a survey of 142 facilities.
Vilaplana and Hushak		Zebra mussel	Lake Erie	$94 average costs for protective paint, $171 maintenance and $207 insurance.	Survey of recreational users increased expenses. Low response rate.
OTA	Early 1980's	Asian Clam		$4.5 million in 1980 and $1 billion in annual losses	$4.5 million figure is compliance costs for nuclear electric industry.

Authors	Time period covered	Species	Geographic area	Dollar Value	Outcomes
Plant Estimates					
OTA		Hydrilla	Florida	$14.5 million annually	Estimated control costs
Pimnetel et al		European loosestrife		$45 million annually	Estimated control costs and forage losses
Rockwell	1984	Aquatic weeds	Florida	$14 million	Aquatic weed control expenditures
Rockwell	1991	Aquatic weeds	Florida	$7.3 million annually	Estimated benefits for residential damage control in 11 Florida counties.
Rockwell	1992	Aquatic weeds	Florida	$5,000-$8,000 per acre	Benefits of control programs to citrus production.
Rockwell	1993	Aquatic weeds	Florida	$300,000	Benefits of control programs to vegetable production.
Rockwell		Aquatic weeds	Illinois, Florida, Alabama and British Columbia	$176,000-$1.3 million	Annual willingness to pay for recreational benefits of weed control.
Rockwell	1986 and 1995	Aquatic weeds	Illinois, Florida, Alabama and British Columbia	$10 million in total economic impacts; $900,000 in 1986 expenditures and $100 million in 1995 expenditures.	Annual willingness to pay for recreational benefits of weed control.
Rockwell		Aquatic weeds	National	$1 - $10 billion	Impacts estimated extrapolating from the Florida estimates.
Rockwell		Aquatic weeds	National	$17 million	Costs to treat (chemicals) weeds estimated extrapolating from the Florida estimates.

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Web Sites on Invasive Species

Aquatic Ecosystem Restoration Foundation
http://www.aquatics.org/index.html

California Department of Fish and Game. Chinese Mitten Crab Site.
http://www.delta.dfg.ca.gov/mittencrab/

Chesapeake Bay Program. Invasive Species in the Chesapeake Bay Watershed Workshop.
http://www.mdsg.umd.edu/exotics/workshop/index.html

Exotic Aquatics on the Move
http://ag.ancs.purdue.edu/EXOTICS/related_links.htm

Invasivespecies.gov: The Nation's Invasive Species Information System
http://www.invasivespecies.gov

Great Lakes Commission : Aquatic Nuisance Species
http://www.glc.org/ans/

Great Lakes Fishery Commission
http://www.glfc.org

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http://www.glfc.org/sealamp/how.asp

Great Lakes Information Network (GLIN): Invasive Species in the Great Lakes Region
http://www.great-lakes.net/envt/flora-fauna/invasive/invasive.html

Global Ballast Management Programme
http://globallast.imo.org/

Integrated Systems for Invasive Species. Ecological Forecasting and Risk Analysis for Nonindigenous Species.
http://www.math.ualberta.ca/~mathbio/ISIS/index.html

Massachusetts Aquatic Invasive Species Management Plan
http://www.mass.gov/czm/invasivemanagementplan.htm

National Aquatic Nuisance Species (ANS) Task Force
http://www.anstaskforce.gov/index.htm#

National Aquatic Nuisance Species Clearinghouse. New York Sea Grant
http://www.aquaticinvaders.org/nan_ld.cfm

National Sea Grant
http://www.nsgo.seagrant.org

National Sea Grant Library. University of Rhode Island
http://nsgd.gso.uri.edu/

National Sea Grant Nonindigenous Species Site (SGNIS)
http://www.sgnis.org/

National Sea Grant Non-indigenous Species Research and Outreach
http://www.nsgo.seagrant.org/research/nonindigenous/index.html

Northeast-Midwest Institute: Biological Pollution - Aquatic Invasive Species
http://www.nemw.org/biopollute.htm

RIDNIS Project. University of California, Davis.
http://www.ridnis.ucdavis.edu/index.html

San Francisco Bay Invasive Species. RIDNIS Project. University of California, Davis.
http://www.ridnis.ucdavis.edu/NISofConcern1.html

Smithsonian Environmental Research Center. Marine Invasions Research Lab.
http://www.serc.si.edu/labs/marine_invasions/

U.S. Geological Service. Nonindigenous Aquatic Species Information Resource.
http://nas.er.usgs.gov/

Western Regional Panel on Aquatic Nuisance Species.
http://answest.fws.gov/

Washington Department of Fish and Wildlife.
http://www.wdfw.wa.gov/fish/ans/greencrab.htm