CHOICES
The magazine of food, farm, and resource issues
3rd Quarter 2006 • 21(3)
A publication of the American Agricultural Economics Association

Overview: Designing and Implementing Invasive Species Prevention, Eradication, and Control Policies: Economics, Biology, and Uncertainty

Rachael E. Goodhue and Gregory McKee, Guest Editors

JEL Classification: Q18

As discussed in the other contributions to this themed set of articles, invasive species may disrupt trade flows, management of natural resources, and agricultural production. An invader may be used as the justification for erecting a barrier to trade. Fishery stocks can be decimated by an invader, requiring the recalibration of quotas, seasons, and other policy instruments. Agricultural yields or output quality may be reduced by an invader. Because of the potential for deliberate introduction, invasive species policy is even a relevant issue for policymakers addressing terrorism.

Invasive species represent a unique challenge for policymakers and for economists analyzing optimal pest control policies because of the uncertainty regarding the effects of an invasive species on pre-existing biological and economic relationships. By definition, an invasive species problem involves the invader's biological and economic interactions with the invaded ecosystem and economic agents involved in that ecosystem. The primary theme unifying these articles is that critical mistakes regarding policy choices can be made if relevant economic and biological relationships are not incorporated into analyses of policy options. Each article identifies a key lesson for invasive species policy analysis.

Articles in this Theme:

Overview: Designing and Implementing Invasive Species Prevention, Eradication, and Control Policies: Economics, Biology, and Uncertainty 129

Bioeconomic Modeling of Greenhouse Whiteflies in California Strawberries 133

On the Garden Path: An Economic Perspective on Prevention and Control Policies for an Invasive Species 139

Institutional Uncertainty at Home and Away: The Case of Lemons from Argentina 143

Invasive Species and the Depth of Bioeconomic Integration 147

Modeling the Depth of Bioeconomic Integration

Finnoff et al. explore the importance of choosing the correct degree of integration within a bioeconomic model. As in McKee et al., in order to address a bioeconomic policy question, feedback between the two systems must be incorporated into the model. Finnoff et al. introduce a bioeconomic model with multiple feedback loops. They examine the effect of imposing quotas on pollock harvests in the Bering Sea in order to increase populations of the endangered Steller sea lion. Fishing quotas affect the market for pollock; in order to estimate the net welfare impacts in this market, the demand for pollock must be included in the bioeconomic model.

Limiting the analysis to this set of bioeconomic relationships would distort the overall welfare analysis in an important way; it does not place any value on the sea lion population, but simply takes it as the source of an exogenous biological constraint on the system, which requires the imposition of fishing quotas. The authors incorporate a second set of bioeconomic relationships that address this problem: the market for wildlife tourism in the Bering Sea, which benefits from increased populations of the Steller sea lion and other marine mammals. Ignoring these relationships would have two effects: first, the sea lion population would either be exogenously specified or chosen as a function of biological relationships alone, and second, the benefits of quotas would be underestimated since the value to marine tourism would be ignored.

The primary lesson from this analysis is that all relevant markets must be included in the bioeconomic model. A further implication is that all relevant biological relationships must be included in the model.

Integrating Prevention and Control Policies for an Invasive Species

Kaiser discusses problems stemming in part from the structure of U.S. invasive species policy. First, responsibility for invasive species policy is divided among a large number of agencies, which discourages the development of an integrated approach to prevention and control. Conceptually, this problem is driven in part by the tendency for prevention efforts to be targeted at preventing the anticipated economic and ecological losses that a given potentially invasive species may cause, while management and eradication efforts tend to be driven by the irreversible changes to ecological systems that are realized after the successful establishment of an invader. One result of this fragmentation is that resources are not allocated efficiently across species, or across prevention and control efforts for a given species. Coordinating policy across agencies, or consolidating mandates within fewer agencies, could increase the benefit of funds currently allocated to prevention and control efforts.

The economic and ecological costliness of the fragmentation of policy responsibility can be represented fully only in a bioeconomic framework. Kaiser illustrates this using the case of an invader to a closed ecosystem: the brown tree snake in the Hawaiian Islands. Limiting attention to biological factors might result in research and policy efforts directed only at preventing an invasion, in part because an earlier brown tree snake invasion on Guam has proven to be ecologically catastrophic. In the case of the brown tree snake, such efforts focus on preventing the introduction of additional specimens through materials transported from Guam. Given that prevention is by nature imperfect, however, some brown tree snakes will escape detection and enter the Hawaiian ecosystem.

Once introduced, the species requires control efforts. Because the marginal cost of control increases as the population declines, optimal policy requires the net benefit of preventing an additional snake from entering the population equals the net benefit of removing an additional snake from the existing population. Hawaiian expenditures on prevention and control are significantly distorted, relative to the point where this relationship would hold.

Hawaiian efforts regarding the brown tree snake approximate the case where only biological parameters are considered. Current annual expenditures on prevention are about \$2.6 million, while expenditures on control are about \$76,000. These limited control expenditures have proved insufficient to identify and reduce the existing population to optimal levels; instead, snakes that have escaped prevention efforts are able to reproduce and increase the population. (Of course, the alternative possibility is that prevention efforts have proven perfectly effective and there is no existing population. However, this seems statistically and scientifically unlikely.) The distortion in prevention and control expenditures will ultimately result in a larger Hawaiian brown tree snake population than would be the case if the same total expenditure was optimally allocated.

Value of Information and Methodological Choices in Bioeconomic Modeling

McKee et al. address one manifestation of the heightened uncertainty facing policymakers regarding an invasive species problem, relative to an established pest problem. Often, policy decisions must be made when relatively little information is available, be it in the form of experimental data regarding the specific invasive species problem or otherwise. In this event, methodological choices become critical because the role of method-driven assumptions cannot be limited by data. Often, due to data limitation, analysts construct simple reduced-form population models where current population levels are estimated based on past population levels. The authors illustrate the cost of this specific methodological choice in the context of a specific invasion: the greenhouse whitefly in California strawberries.

The authors construct two bioeconomic models of the greenhouse whitefly-strawberry relationship. The economic components of the models are identical, as is the relationship governing the effect of the whitefly population on strawberry yield. Only the models of the whitefly population differ. One is a reduced-form autoregressive model that relies only on experimental data to predict the development of the whitefly population as a function of its previously observed levels. The second is a structural simulation model that incorporates information regarding determinants of the whitefly's life cycle from the scientific literature, as well as the experimental data regarding observed population levels.

The two models are compared to the observed data. While both describe the overall pattern of population peaks and troughs reasonably well, the structural simulation model does a more accurate job of representing the magnitudes of the peaks and troughs. This suggests that incorporating data from other sources and constructing a structural simulation model can improve the descriptive power of bioeconomic models, at least in some circumstances. More critically, the authors demonstrate that this difference in the models causes growers to respond differently to regulations regarding pesticide use for whitefly control in strawberries. Using the reduced-form model, the cost per acre to a grower of the regulation limiting the number of applications of a specific pesticide to two per season is $2,500, while under the structural simulation model it is $2,100, a difference of $400 dollars per acre. This difference in the estimate of the cost is substantial, equaling about 10% of profits under the grower's unregulated profit-maximizing choice. When balancing the costs of the regulation against its benefits in terms of reducing the development of resistance, the cost will be overstated.

Institutional Uncertainty and Bioeconomic Systems

One motivation for the erection of agricultural trade barriers is the possibility of an invasion of a pest or disease that may negatively affect production in the importing country. Romano and Thornsbury examine a specific case: a U.S. ban on the importation of Argentine lemons due to diseases not present in the United States. In efforts to get the ban removed, Argentina's citrus producers developed a set of institutions to develop and implement a systems approach to phytosanitary regulation.

A systems approach to invasive species policy involves multiple control steps at different stages of production and marketing. The use of multiple, sometimes independent, control steps is intended to reduce the risk of an invasion. Successful implementation of a systems approach can be technically and politically difficult. Technically, a systems approach requires an understanding of the production and marketing chain, as well as the biology of the crop and pest in question. Institutions must be capable of mastering these technical elements and be able to undertake multiple control steps. Politically, the feasibility of implementing a systems approach in order to enable the removal of a trade barrier depends on the credibility of the institutions regarding their ability to master these technical requirements, as well as on the political influence of competing interest groups and the parameters set by international trade rules.

Such political considerations are made more powerful by uncertainty. When information regarding a bioeconomic system is incomplete, then a systems approach to regulation must be implemented based on the information available. Different stakeholders may assess the costs of the resulting risks, or even the risks themselves, very differently. Romano and Thornsbury identify U.S. growers' reluctance to allow imports based on information provided by U.S. and Argentinian institutions as "institutional uncertainty." Concerns regarding the quality and quantity of the provided information have played an important role in the still ongoing trade dispute. Clearly, when deciding how much information to obtain prior to choosing a policy, the information collection decision should be guided by the economic consequences of making a mistake, and the cost and likelihood of doing so as a function of the amount of information collected.

Lessons for Policy Analysis

Bioeconomic modeling provides a means of incorporating known information into a single decisionmaking framework. There is a great deal of uncertainty regarding the bioeconomic relationships determining the optimal policy response. The analyses in this set of articles derive four specific lessons regarding the use of bioeconomic models in invasive species policy analysis: First, all relevant economic and biological relationships must be included in the model in order to get a full picture of the benefits and costs of potential policies. Second, a complete analysis of policy choices regarding potential invasions should include not only the optimal management, eradication, or prevention policy, but a comparison of these optimal solutions that balances the marginal benefits of funds allocated to each activity. Third, methodological choices will affect estimates of these marginal benefits; alternatives to statistical methods that can incorporate additional information should be considered. Simulation models provide a means of identifying the unknown parameters that are most likely to affect the choice of the optimal policy solution. Finally, information collection efforts should be guided in part by the projected costs and probability of making policy mistakes in the absence of this information.

In sum, invasive species policymaking is a process, rather than a single decision. Bioeconomic modeling can play a role at every stage of the process, from representing the context for choosing the initial policy, identifying missing information that's important for assessing the impacts of that policy, assessing post-implementation impacts, and providing information for revising existing policies. This set of themed articles has identified guidelines for using bioeconomic models effectively in the policymaking process.

Rachael Goodhue is Associate Professor, Department of Agricultural and Resource Economics, University of California, Davis, and a member of the Giannini Foundation of Agricultural Economics. Gregory McKee is Assistant Professor and Director of the Quentin Burdick Center of Cooperatives, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo, ND.
This research was supported by the Program of Research on the Economics of Invasive Species Management (PREISM), Economic Research Service, U.S. Department of Agriculture, under Cooperative Agreement 43-3AEM-3-80081. Seniority is shared equally between authors.

CHOICES
The magazine of food, farm, and resource issues
3rd Quarter 2006 • 21(3)
A publication of the American Agricultural Economics Association

Bioeconomic Modeling of Greenhouse Whiteflies in California Strawberries

Gregory McKee, Colin A. Carter, James A. Chalfant, and Rachael E. Goodhue

JEL Classification: Q18

When a species invades an agricultural system, policymakers and producers need ways to compare the cost and benefits of control alternatives. In this paper, we examine the greenhouse whitefly invasion of California strawberries and a set of control alternatives, along with the effects of the information included in the analytical framework.

The greenhouse whitefly invasion into California strawberries has three economic and biological characteristics that make it a particularly interesting case. First, restrictions associated with pesticides registered for use against the greenhouse whitefly (hereafter called the whitefly) create a complex management problem. Only one chemical was registered for use against whiteflies on strawberries during the harvest period, pyriproxyfen (Esteem). Furthermore, regulations limiting the number of Esteem applications to strawberries complicate management. Namely, the Environmental Protection Agency has imposed a limit that only two applications of Esteem may occur per year.

Second, the whitefly's life cycle can be modeled plausibly based on data from a single season. The resultant model can be used to study management alternatives and to guide data collection efforts for other invasive species by revealing key parameters associated with population development and interactions with economic activities. Third, the whitefly is a significant economic problem in two geographically separate California regions. The climate and other differences across these regions create different host cycles and whitefly population dynamics, which then lead to differences in decisions concerning whitefly management.

The biological, economic, and regulatory features of the invasion cause grower incentives for whitefly control to vary by region and by week. Therefore, in order to create economically and environmentally efficient whitefly management policies, an understanding is needed of a grower's profit-maximizing response to pest damages. Empirical "bioeconomic" models, which unify information on biological relationships, economic relationships, and interactions between them, are useful in developing such policies (McKee, 2006; McKee, Goodhue, Chalfant, & Carter, 2006; Eiswerth & Johnson, 2002; Knowler & Barbier, 2000).

Also, when doing invasive species modeling it is often the case that limited information is available. In this study, we examine the value of adding information first using only data arising soon after the establishment of the whitefly population and then adding other information about the whitefly's life cycle from the scientific literature.

Models of Whitefly Population Development in California Strawberries

The whitefly invasion started in the mid-1990s in Ventura County and was later observed in the Watsonville/Salinas strawberry-growing region (Monterey and Santa Cruz Counties). Though whiteflies were common in coastal California prior to that time, strawberries had not been recorded as a host.

Strawberries are grown along the California coast almost year-round. A plant is typically in the ground for approximately nine months, usually starting in the fall. Weekly yields are relatively small in the early spring, increase very rapidly in mid- to late-spring, and then taper off during the summer. The population growth rate of the greenhouse whitefly on strawberries changes throughout the season since temperature regulates maturity rate. Whitefly reproduction and population development are slowest during the coolest parts of the growing season and

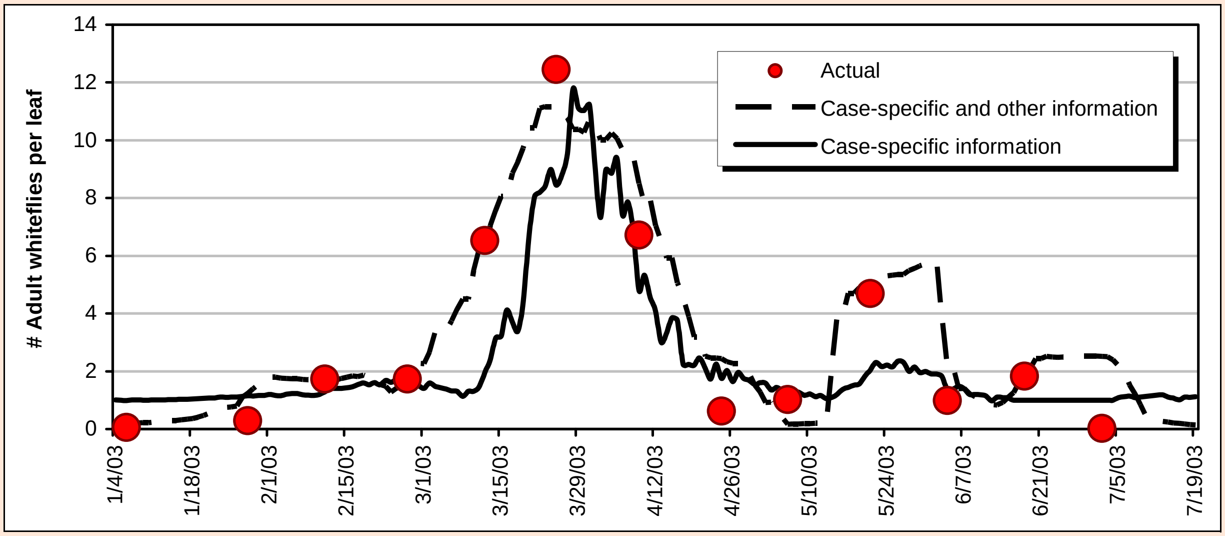

Figure 1. Modeled and observed adult whitefly populations in strawberry plants for a commercial strawberry field, Watsonville, CA (2003).

more rapid during the hotter, spring and summer months.

Alternative Approaches to Modeling

We use statistical techniques to predict the future whitefly population. Initially, we only use data from the invasion during the 2002-2003 growing season. This requires limited relatively immediate data and permits rapid model and policy development. However, it may omit important biological factors, such as variations in the population growth rate over time, if no such data are available. Later, we augment the approach with information from whitefly studies in similar environments utilizing results on various life stages. This may also be an attractive option since the costs for data collection have already been incurred, and only an analysis of emerging information is needed. However, the main question is whether data obtained from outside sources are relevant.

Thus, two models are used. The first estimates a daily adult population series using egg count data from the invasion. The second uses invasion egg, nymph (juvenile whitefly), and adult whitefly data, along with observations from other whitefly studies (Hulspas-Jordaan & van Lenteren, 1989) to inform the model about how variations in environmental conditions affect whitefly population development. The additional population data were acquired at little additional cost.

Results

In order to assess control alternatives we compare estimated net revenues, after spraying costs and population predictions, under various strategies using the two models.

Model Replication of Population

We first evaluate the model results to see which model replicates the observed data better. If the two models both adequately reflect the whitefly population dynamics, then the estimated population series should be comparable. If they are not, this indicates that information is lost when the augmenting experimental information is not used. If a significant difference is observed, then the additional information allows more accurate and effective evaluation of prospective whitefly management policies.

The solid line in Figure 1 represents the estimated adult whitefly population series from the first model; the dashed line represents the second. The 13 large dots represent the observed sample. As the figure shows, both models reasonably predict the timing of peaks and troughs in the whitefly population.

One way to more precisely compare the results of these two models is to measure the area under each curve. This area measures the size of the population and the length of time it persists, stated in units we call "whitefly-days." There were 505 cumulative whitefly-days observed in the sample. The first model (case-specific data only) predicts 430 whitefly-days (15% error), while the second predicts 564 cumulative whitefly-days (10% error). Based on this criterion, the second model generates a superior prediction.

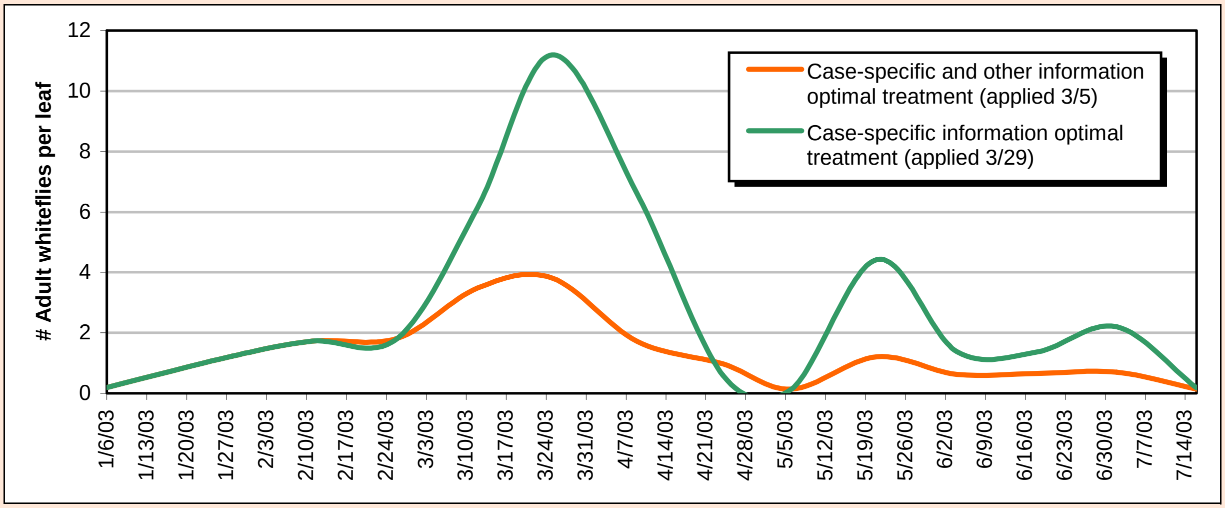

Figure 2. Whitefly population development under low/high information models.

Information and Costs of Esteem Limits

Fundamentally, what matters is not the existence of a difference in predictive power, but whether or not there is a substantive economic consequence when evaluating a policy option. To address this question, we examine net revenue and population changes caused by Esteem application restrictions. The optimal application program in each model is the one with the largest net revenues.

We first examine the difference in the model results regarding the development of the whitefly population for the case of a single Esteem treatment, illustrated in Figure 2. When using the first model, the optimal date for a single Esteem application is March 29, just after the largest observed adult whitefly population peak. In contrast, the additional information used in the second model changes the optimal pesticide application date to March 5th, just before the adult whitefly population begins to build. Prior to March 5, the populations are identical. The population generated by the March 5 application generates smaller population peaks than the March 29 application, and higher net revenues. Collectively, the more accurate model results in a difference of approximately 3% of net revenue per untreated acre.

To provide further perspective, we examine the cost of the Esteem regulation limiting growers to two or fewer applications per season. Using the second model, under two applications we get about $7,800 per acre, as opposed to about $9,500 per acre for three, a regulation cost of about $1,700 per acre. In contrast, under the simpler model the net revenues from the restricted case are about $4,700 per acre, compared to about $7,000 per acre for the relaxed case, which is a difference of about $2,300 per acre.

The added information suggests the cost of the regulations is smaller under more informed pest management, amounting to 18% versus 33% of net revenue. The benefit is partially due to the difference in the optimal spraying time, and partially due to the more accurate representation of post-treatment population development. Based on about 1,000 infested acres in 2003, the value of relaxing the application limit would have been $1.7 million, in net revenue, per year. However, additional applications would have increased the likelihood of resistance, and if complete resistance arose we estimate losses relative to the two-application case would be about $7.8 million per year. While this is obviously a very simplistic view of the implications of resistance, it illustrates how large the benefits from preventing or delaying the development of resistance can be in this specific case.

The weaknesses of the first model suggest that for decisionmaking support it would be valuable to merge experimental data on pest life cycle stages with other known information. Of course, if unlimited data were available, the performance of the first model would be augmented including other relevant variables. However, our model comparison was motivated by the often limited data available for policymakers examining invasive species policy options, as existed in the case study we examined.

What Types of Models should Policymakers and Growers use for Decisionmaking?

When a species invades an agricultural system, policymakers and growers require integrated bioeconomic models in order to evaluate control options. When constructing these models, there is an inevitable tradeoff between implementing a control approach early in the invasion and waiting to collect data specific to the invasion in order to make a more informed decision. We have examined addressing this tradeoff by combining scientific information from other sources regarding the whitefly with available data from its invasion of California strawberries. Using readily available data and physiological models to estimate the economic harm the greenhouse whitefly causes—decreased strawberry yields—generates a more accurate whitefly population prediction than one that only uses case-specific data.

We found that the difference in the population models substantially affected the estimates of the per-acre cost of the Esteem application limit for growers. Using only data from the invasion, the cost was $2,300 per acre, or $2.3 million in the infested area. Using the augmented model, the cost was $1,700 per acre, or $1.7 million in the infested area.

Our analysis of this specific case illustrates that information on the life cycle of the pest, when available, can improve decision making. Namely, the model with more information is better able to describe the feedback between grower management decisions and the invader/host plant environment. Policymakers need to determine whether or not they need to intervene in the system. In our case, regulators were concerned about the possibility of the whitefly developing resistance to the only effective control treatment prior to the development of alternative treatments. Using the augmented model resulted in a 26% lower estimated per-acre cost of complying with the requirement of two or fewer Esteem applications in order to obtain the benefit of a decreased likelihood of resistance development. Of course, the off-setting caveat is that the modeler must make careful decisions regarding which outside information is sufficiently relevant.

For Further Information

Eisworth, M., & Johnson, W. (2002). Managing nonindigenous invasive species: Insights from dynamic analysis. *Environmental and Resource Economics*, *23,* 319-342.

Knowler D., &. Barbier, E. (2000). The economics of an invading species: A theoretical model and case study application. In C. Perrings, M. Williamson, & S. Dalmazonne, (eds.), *The economics of an invading species.* Cheltham, UK: Edward Elgar Publishing, Ltd.

Hulspas-Jordaan, P., & van Lenteren, J. (1989). Modeling population growth of the greenhouse whitefly. *Wageningen Agricultural University Papers*, 89-92.

McKee, G. (2006). Pesticide resistance, population dynamics, and invasive species management. Doctoral dissertation. University of California, Davis.

McKee, G., Goodhue, R., Chalfant, J., & Carter, C. (2006). Modeling the effect of spatial externalities on invasive species management. Presented at the 2006 AAEA Annual Meetings, Long Beach, CA.

Osborne, L. (1982). Temperature-dependent development of greenhouse whitefly and its parasite. *Encarsia formosa*. *Environmental Entomology*, *11,* 483-85.

Perrings, C., M. Williamson, and S. Dalmazonne. (2000). Introduction. In C. Perrings, S. Dalmazonne, and M. Williamson, *The economics of an invading species*, pp.1-16. Cheltham, UK: Edward Elgar Publishing, Ltd.

Sumner, D. (2003). Economics of policy for exotic pests and diseases: principles and issues. In D. Sumner (ed.), *exotic pests and diseases: Biology and economics for biosecurity.* Ames, IA: Iowa State University Press.

Gregory McKee (Gregory.mckee@ndsu.edu) is Assistant Professor and Director of the Quentin Burdick Center of Cooperatives, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo, ND. Colin Carter (cacarter@ucdavis.edu) and James Chalfant (jachalfant@ucdavis.edu) are Professors and Rachael Goodhue (goodhue@primal.ucdavis.edu) is Associate Professor, Department of Agricultural and Resource Economics, University of California, Davis, CA. Carter, Chalfant, and Goodhue are members of the Giannini Foundation of Agricultural Economics.

This research was supported by the Program of Research on the Economics of Invasive Species Management (PREISM), Economic Research Service, U.S. Department of Agriculture, under Cooperative Agreement 43-3AEM-3-80081. The authors thank Frank Zalom for providing the greenhouse whitefly population data and the strawberry yield-greenhouse whitefly population data, which are the basis of the biological models. This article is based on a portion of Chapter 5 of McKee's dissertation, supervised by Goodhue, Carter, Chalfant, and Zalom. The authors thank Jeffrey Williams for many useful conversations regarding this work, and Bruce McCarl for his helpful suggestions. All mistakes and omissions remain the responsibility of the authors.

CHOICES
The magazine of food, farm, and resource issues
3rd Quarter 2006 • 21(3)
A publication of the American Agricultural Economics Association

On the Garden Path: An Economic Perspective on Prevention and Control Policies for an Invasive Species

Brooks A. Kaiser

JEL Classification: Q20, Q57

Economists currently use the term invasive species to denote species that arrive in a new ecological setting and spread, creating ecological and economic damages. The problem facing invasive policy managers is to select strategies that minimize the overall invasive species-related costs over time, including prevention and control expenditures and damages. This article aims to highlight the connection between prevention and control in decisions to best utilize scarce resources to fight invasive species and arises from a more extensive literature involving this author and others (Burnett et al., 2006; Olson & Roy, 2005).

Definitions and the Policy Environment

An invasive species generally causes more harm than good through its aggressive spread. Prevention efforts, however, cannot always identify distinctions between harmful, beneficial, or benign introductions, nor intercept all introductions, and are thus more risky policies compared to controlling a known invader. Thus, risk-averse managers often prevent too little (Finnoff et al., 2006, in press).

Opportunities for efficient management of invasive species from arrival to adaptation are missed in a web of overlapping mandates and complex biological and economic pathways for the introduction and spread of species. Historically, the many different avenues for invasive species propagation and intervention have led to piecemeal policy approaches to invasive species. Twenty federal agencies, from the Department of Homeland Security to NASA, administer over a dozen major congressional acts pertaining to invasive species. Executive Order 13112 (Feb. 3, 1999) acknowledged the difficulties presented by this piecemeal policy and established a coordinating interdepartmental National Invasive Species Council (NISC), but the agency has no authoritative powers, and policy conflicts and gaps remain.

Consider the differences in legislative policy:

- There are acts targeting individual species (Sudden Oak Death, Pub. L. 108-488, Dec. 23, 2004; Brown tree snake, Pub. L. 108-384, Oct. 30, 2004; Nutria, Pub. L. 108-016, Apr. 30, 2003). These exist despite the fact that there is no definitive reason to believe that these invaders are worse threats than all others; however, the targeted legislation may limit attention toward other equally damaging prospects.
- There are direct, broad mandates to reduce harm from non-native species (Plant Protection Act, Pub. L. 106-224, Jun. 20, 2000; National Invasive Species Act, Pub. L. 104-332, Oct. 26, 1996; Lacey Act, 18 USC §42). Most of these focus on preventing the introduction of new invasive species that are likely to harm agriculture or other markets or quantifiable resources.
- There are statutes that indirectly target invasive species prevention and control for the preservation of specific assets (Public Lands Corp Healthy Forest Restoration Act, Pub. L. 109-154, Dec 30, 2005; Endangered Species Act, 16 USC §1531-1539). These statutes generally apply control measures after invasion as indirect intervention for the protection of non-market amenities such as biodiversity.

As such, the biological and economic consequences of individual species *and our awareness of these species and their consequences* may generate poor allocation of resources among species. The net benefits or damages of an introduced species may vary significantly depending on the state of the existing ecosystem. For example, using exotic plant species for quick stabilization of denuded hillsides might bring significant benefits by mitigating massive flooding in one location, whereas introduction of the same species in another location may reduce biodiversity or water supply. Intertemporal considerations abound; today's quick fix may be tomorrow's bane.

Economic and Biological Considerations in Invasive Species Control

The problem facing invasive policy management is to minimize the expected net damages and prevention and control costs of new and existing invasions over time. This problem is also subject to the biological constraints of the species. Figure 1 illustrates how a species whose minimum viable population (E_i) is low and that grows rapidly to a large carrying capacity population (K_i) is most likely to invade successfully. One whose initial population threshold (E_n) is higher, requiring a higher initial volume of arrivals, whose growth rate is slower, allowing for more time to eradicate, control, or contain a spreading population, and whose carrying capacity population is lower(K_n), does not present the same biological threat. Furthermore, a lower initial population threshold, such as (E_i), makes eradication considerably more costly as a smaller population must be located and removed. Research and prevention policies might therefore focus on identifying and stopping species from entering based solely on their biological parameters.

However, biologically driven policies may not always target the correct species with the most efficient efforts. The biological potential of a species must be combined with economic theory and the expected damages and costs of control for the species. We discuss how the characteristics of damages and costs impact prevention and control decisions.

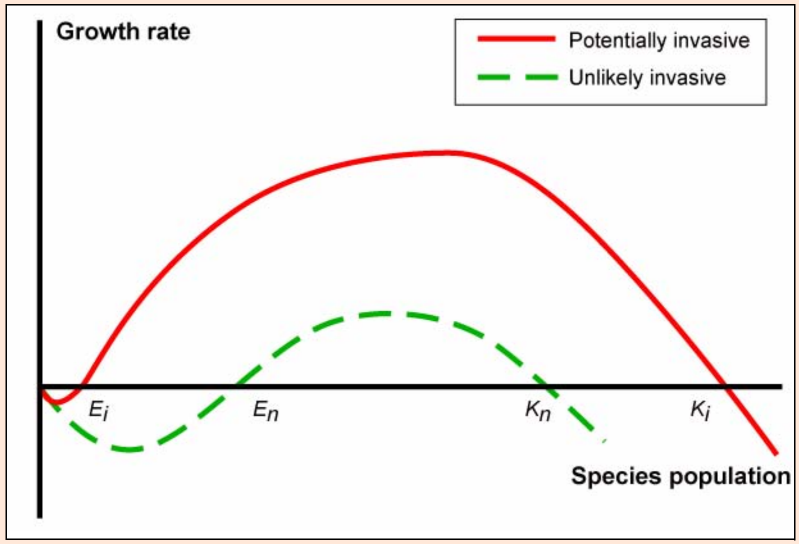

Figure 1. Role of biological growth.

Damages may be economic or ecological. Economic damages are generally in the forms of direct damages to facilities, human health, natural resources, and indirect damages from ecological change. Ecological change may commonly include losses in water or soil quality or quantity, biodiversity and resiliency losses, and productive resource losses. The expected damages are a function of the invasion size. In many cases, ecological damages may outweigh economic ones. This is likely when the value of the threatened assets is generated from biodiversity, tourism, aesthetics, and the like. Non-market valuation techniques may be necessary to establish these damages (See Loomis, 2005). We can use information on these characteristics to determine the expected damages from taking no action, or accommodating the invasion, and the benefits from control across a spectrum of invasion sizes corresponding to policy choices and expenditures.

Economic Conclusions Related to Invasive Species

Though similar to the harvest problem of any renewable natural resource (Clark, 2005), in which management weighs the net benefits of harvest (removals) today against the net benefits of future harvests, invasive species problems are more likely to involve cases where extinction is optimal policy or where accommodation of the damages, without control efforts, is the best choice. Determining the appropriate policy is particularly complicated when there are significant biological uncertainties surrounding the invasive species' capabilities in a new ecosystem and when there are difficulties in measuring resource values, such as with many non-market amenities. It is useful, therefore, to determine some rules of thumb regarding these parameters.

- Control policy must consider the overall cost of controlling an invasion.

If the net benefits from the invasive species removal (harvest) outweigh current control costs, conserving the species for tomorrow does not generate a net economic benefit, and biological extinction, or eradication, may well be the optimal policy. If the costs of harvest outweigh the damages of the population, it may be optimal to allow the species to invade unchecked. All other factors equal, lower levels of damages or high costs relative to the damages will decrease control activities, as will time-delayed damages.

- Control policy must consider the cost of controlling an invasion as a function of the size of the invasion so that the benefits of controlling or preventing the invasion may be weighed against the costs of doing so.

Once a species is established, we expect that the per pest cost of control will generally increase as the size of the population decreases. This is due to increased difficulty in detecting and removing fewer and fewer specimens from any given area. All other factors equal, the higher the costs of removal, the larger the population that will be accommodated, once present.

- The degree of rise in cost as control efforts increase also plays an important part in control policy.

A relatively flat cost structure is more likely to result in accommodation than a cost relation that drops off to lower levels at higher populations. On the other hand, fast increasing costs may favor eradication followed up by prevention of re-introduction.

- Policy should also weigh the intertemporal advantages, in terms of present discounted value, of preventing or removing an additional invasive specimen today against those of leaving the problem for tomorrow.

The role of prevention, either before an initial arrival or after a successful eradication, should also be integrated into policy formation. Prevention efforts should be based on the expected outcome if prevention fails. Since prevention is imperfect, over time the cumulative probability that a new species will evade detection and establish itself is nearly one. Prevention expenditures delay this establishment, but cannot eliminate it altogether. When prevention fails, the species will establish and begin to grow and cause damages. Thus, prevention expenditures for a given species should continue until the point where the cost of preventing the next specimen from entering is equal to the cost of controlling another specimen on the ground.

- A species' ability to spread will significantly impact the costs of control.

For example, if the species needs a relatively large population to maintain itself, as visualized by E_n in Figure 1, reducing the population to this extinction level, rather than to zero, negates further control costs, though the population is not eradicated. Optimal policy determining effort allocations between prevention and control at small population levels may involve only prevention, only control, or a combination of prevention and control, and are quite sensitive to the biological and economic parameters of the system.

- Across species, the marginal benefits of prevention and the costs of control activities should also be equal.

The relationship between prevention and control, therefore, may be quite complicated. For example, it is not clear whether prevention should be high or low for a species whose optimal control policy after establishment is accommodation; if this is the case due to control costs that are always higher than damages, in spite of high damages, then prevention should be high, in order to delay the damages. If, however, accommodation is the policy because the present value of damages is quite low, then optimal prevention might also be low.

A Case Study: Brown Tree Snake Prevention in Hawaii

The economic reasoning described here has been applied to the cases of the Brown tree snake in Hawaii with interesting results (Burnett et al., 2006). The Brown tree snake is a significant concern to the Hawaiian Islands because of its behavior on Guam over the past 50 years. Both Guam and Hawaii were snake-free islands until the Brown tree snake arrived in Guam sometime in the 1950s. Since that time, its unchecked predation has led to some of the highest snake densities known in the world, caused extirpation of 10 of 13 native bird species and caused significant economic damage to power supply and human health. Eight specimens have been intercepted in Hawaii in transported materials from Guam. A small but uncertain number may have escaped detection in Hawaii already. The carrying capacity for Hawaii is estimated at almost 39 million snakes and the damages are conservatively estimated at an average of $122 per snake per year from losses in biodiversity, power supply, and medical expenditures (Burnett et al., 2006).

It might seem that almost no amount of prevention expenditures could be too high to avoid these damages. The old adage that "an ounce of prevention is worth a pound of cure" comes to mind, but unfortunately, it may not be true. In cases like this where prevention is focused on a small number of expected pathways, while control of a small population might require searching over a large area at high cost, lavish prevention expenditures will not successfully minimize the threat from invasion. If one is not actively searching the broader habitat for the specimens that avoid detection through prevention mechanisms, these may rapidly reproduce and grow beyond a stage where they are eradicable or easily contained.

In the case of the Brown tree snake, such oversight could be extremely expensive. If, for instance, the current mix of prevention and control is pursued without change, $2.6 million per year will be spent on preventing the species from reaching Hawaii, but about $76,000 will be spent on searching for snakes that evade prevention efforts. Since these have proved to be insufficient funds to catch a snake from a very small population, under status quo efforts, the existing population will continue to grow until there are enough snakes that this limited annual expenditure results in catching a snake, imposing perhaps billions of dollars of silent damages in the meantime. Instead, if there indeed is an existing population in Hawaii, it would be preferable to spend much more of the prevention money on ferreting out that population and limiting damages directly. An additional avenue for reallocating the prevention money might be toward joint production of snake removals with other conservation activities, should such a possibility exist.

Concluding Comments

In sum, prevention and control decisions must be integrated thoroughly to best utilize scarce resources to fight invasive species. Policy must consider that invasive species are a function of human trade and discourse, which is increasing in even the most remote corners of the globe. Optimal strategies will vary by anticipated biological growth, economic cost of prevention and control activities, and economic valuation of potential damages as a function of invasion level. Assessment of these parameters may require creative and iterative interdisciplinary processes. Closed ecosystems like Hawaii provide excellent natural labs for study and are important purveyors of irreversible assets, particularly biodiversity, that deserve particular attention in the battle against invasive species.

For More Information:

Burnett, K.M., Kaiser, B.A., Pitafi, B.A., & Roumasset, J.A. (2006). Prevention, eradication, and containment of invasive species: Illustrations from Hawaii. *Agricultural and Resource Economics Review 35*(1), 63-77.

Clark, C. (2005). *Mathematical bioeconomics: The optimal management of renewable resources, 2nd Ed*. Hoboken, NJ: Wiley-Interscience.

Finnoff, D., Shogren, J.F., Leung, B. & Lodge, D.M. (in press). Take a risk-preferring prevention over control of biological invaders. *Ecological Economics.* Available online: http://www.elsevier.com/locate/ecolecon.

Loomis, J. ed. (2005). Valuing the Quality of the Environment and Human Health, *Choices 20*(3). Available online: http://www.choicesmagazine.org/2005-3/index.htm.

National Invasive Species Information Center (2006). Available online: http://www.invasivespeciesinfo.gov/.

Olson, L., & Roy, S. (2005). On prevention and control of an uncertain biological invasion. *Review of Agricultural Economics, 27*(3), 491-97.

Reimer, N, Beardsley, J.W., & Jahn, G. (1990). Pest ants in the Hawaiian Islands. In R.K. Vander Meer, K. Jaffe, & A. Cedeno (Eds.), *Applied Myrmecology: A World Perspective* (pp. 40-50). Boulder, CO: Westview Press.

Brooks A. Kaiser (bkaiser@gettysburg.edu) is Associate Professor, Department of Economics, Gettysburg College, Gettysburg, PA, and Affiliate Graduate Faculty, Department of Economics, University of Hawaii, Manoa, HI.

CHOICES
The magazine of food, farm, and resource issues
3rd Quarter 2006 • 21(3)
A publication of the American Agricultural Economics Association

Institutional Uncertainty at Home and Away: The Case of Lemons from Argentina

Eduardo Romano and Suzanne Thornsbury

JEL Classification: F13, Q17, Q18

Ultimately, the success of any trade relationship depends on achieving satisfactory levels of trust and confidence among trade partners. Uncertainty in such relationships has increased with the adoption of World Trade Organization [WTO] regionalization criteria. An important, and often overlooked, aspect of these criteria governing invasive species regulation is the degree of confidence and trust among regulatory agencies to conduct pest risk assessments, monitor changing conditions, and enforce standards (Thornsbury & Romano, 2002).

One policy response has been increased use of a systems approach; multi-step sanitary and phytosanitary regulations designed to reduce pest risks (USDA APHIS, 2002).[1] We rely on an ongoing case to illustrate attempts to alleviate uncertainty and the complexity of negotiations over policies to manage invasive species risk.[2] Specifically, we examine efforts by Argentina to gain access to U.S. lemon markets illustrating

- how private/public partnerships can build institutions in developing countries to increase the likelihood of access to new markets;
- linkages between institution building and increased trust between trade partners; and
- pressures from industries at home.

Pests of Concern

Argentina is currently the largest lemon producer in the world with approximately 30% of global production (more than 1 million metric tons a year) and a large exporter (more than 330,000 metric tons annually), mainly to European countries (Figure 1). Despite gaining entry to Europe and Japan, Argentine lemons are banned from U.S. markets. In the 1960s, Argentina was only a modest lemon producer with most orchards concentrated in the humid Northeastern states, where the plant disease citrus canker is prevalent. Concern over inadvertent transfer of citrus canker was a primary reason for the original U.S. ban on Argentine citrus (USDA APHIS, 1998b).[3]

Citrus canker is a highly contagious bacterial disease that causes leaf loss, premature fruit drop, and lesions on leaves, stems, and fruit. It is endemic in some major citrus-producing regions of the world (i.e., Brazil), but is generally considered manageable for fruit that will be further processed. The canker alters exterior appearance with a major impact on fresh fruit sales.

1. *An example includes a requirement to test for pathogen presence (step 1) and mandatory pesticide application (step 2), regardless of the outcome of step 1. These measures are independent and risk reduction is additive: if there is a failure in step 1 (the test is negative when in fact a pathogen is present), then there is not an automatic failure in step 2 (USDA APHIS, 2002). Such practices are applied to fresh avocado imports from Mexico into the United States (e.g., Orden & Romano, 1996).*
2. *There are many other examples of disputes over such policies. For example, in 2005, USDA identified 41 trade issues involving potential impediments to U.S. horticultural exports (USDA FAS, 2005). In addition, 33 complaints were raised in the WTO Sanitary and Phytosanitary Committee between 1995 and 2002 regarding policies governing trade in horticultural products (Roberts & Krissoff, 2004).*
3. *Other pests of concern were later identified by APHIS (fruit flies, sweet orange scab, and citrus black spot).*

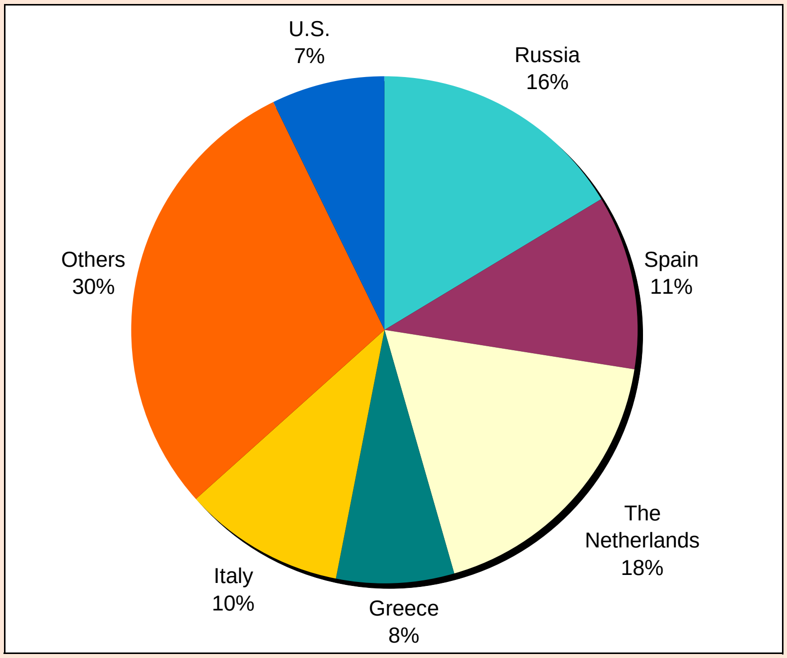

Figure 1. Destination of Argentine lemon exports, 2001. Year 2001 was chosen to show U.S. participation. For years other than 2001, exports to the U.S. equal zero.

In the early 1990s, a group of Argentine businessmen hoping to expand exports planted substantial citrus acreage in four Northwest Argentina states free of citrus canker. In 1991, citrus producers, processors, and exporters in this area established the Phytosanitary Association of Northwest Argentina (called AFINOA), a grower-sponsored institution with a goal of fostering cooperation to implement sanitary and phytosanitary [SPS] practices that would help promote citrus exports. The investors' plan was to apply modern technologies to produce fruit targeted towards European and American markets.

A Challenge to Argentine Institutions

In 1993 Argentina requested entry for fresh grapefruit, lemons, and oranges from the Northwest area to the United States. In 1994, a group of U.S. Animal and Plant Health Inspection Service [APHIS] pathologists visited to assess conditions. Preliminary results indicated that, although the region appeared to be canker-free, it did contain citrus black spot and sweet orange scab, two citrus fungal diseases not present in the United States. In 1995, APHIS denied the request for entry unless canker-free status could be documented and treatments for the other two diseases approved (Harlan Land Co. v. USDA, 2001).[4]

4. *The United States was not canker-free at this time since the plant disease had been detected in the Miami-Dade County, Florida area during 1995. An aggressive eradication program was underway, and avoidance of additional pest entry was considered critical to success. The U.S. eradication program included quarantine restrictions on movement of domestic product as well.*

The Argentine regulatory agency was neither willing nor able to satisfy U.S. concerns and the process stalled in a political dispute. The U.S. position requested scientific evidence of pest-free status. The Argentine position stated that, since European Union-approved policy allowed citrus imports from Northeastern pest-free orchards located in nonpest-free states, the risk of transferring disease from regions deemed pest-free had to be negligible. The Argentine position failed to acknowledge the myriad of different elements and conditions that influence species invasion across geographic areas, as well as different risk preferences and thresholds among potential importers. This illustrates how difficult it is for regulators in a developing country to understand the importance of following established sanitary protocols and to demonstrate scientifically proven phytosanitary health.

To some extent, this controversy underscores the differences in American and European approaches to invasive species management. While APHIS followed the WTO's regionalization principle to allow imports from certified pest-free regions, Europe followed protocols based only on identification of pest-free orchards (FVO, 2002). Momentum to break the impasse came from the Argentine grower organization AFINOA. This group enlisted the academic community to provide scientific expertise to satisfy the requests from APHIS. In addition, the grower organization gathered political support from the Governors of Northwest Argentina to improve and document phytosanitary measures insuring separation of products from pest-free regions. To address U.S. concerns over institutional uncertainty, the Government of Argentina began to elevate the status of its regulatory and enforcement agencies, developing a new institutional umbrella (National Agrifood Health and Quality Service, or SENASA in Spanish).

Subsequently APHIS, given the scientific surveys and research results in 1996, in turn issued a supplemental pest risk assessment, which estimated that the median chance for establishment of pests of concern in the United States was negligible (1 in 3.2 million). In August 1998, APHIS published a proposed rule that allowed citrus imports using a systems approach to guard against black spot and sweet orange scab (USDA APHIS, 1998a). Included were safeguards at the grove and post-harvest levels, a phytosanitary certificate, cold treatment, disease detection protocols, and limitations on distribution and repackaging. Responding to the need to understand and accommodate APHIS' requirements, Argentina was able to move the process forward despite initial mistrust. As a result, the dispute evolved into a less-trade-restrictive protocol based on multiple safeguards built into the systems approach.

Still, increased trust among regulatory agencies had not been transferred to U.S. growers and public comments to the proposed rule revealed continued opposition. Concerns were raised about the scientific basis and execution of the systems approach. Meanwhile, regulatory officials were confident in the scientific merits of the proposal and APHIS moved forward with other aspects of the process. In late 1998, an economic analysis determined that the rule "[would] not have a significant economic impact on a substantial number of small entities" (USDA APHIS, 2000). An environmental assessment was published, which concluded there was negligible environmental risk but if the systems approach failed, the subsequent environmental impact would be "considerable" (USDA APHIS, 1998b).

An Extract of the Court Ruling

1. "Having reviewed the Risk Assessment, the court concludes that the final rule is arbitrary and capricious because it is based on a faulty risk assessment. The uncertain nature of the Risk Assessment is illustrated by the fact that the risk of citrus black spot introduction increased significantly under the revised Risk Assessment from one chance in 3.2 million to one chance in 763,000 for the mean and from one chance in 840,000 to one chance in 189,000 for the 95 percentile. Although the risk is still lower than the risk of fruit fly introduction, where there is one chance in 350,000 for the mean and one chance in 93,000 for the 95 percentile value, the fact that there was a four-and-a-half fold increase in the risk of citrus black spot introduction at the 95 percentile because of faulty assumptions made by the APHIS scientists suggests that APHIS needs to reevaluate the Risk Assessment."

2. "Although the Risk Assessment take (sic) human error into content (sic), it may have understated human error in light of SENASA's failure to report the foot-and-mouth disease. Frankly, the court is concern (sic) about whether SENASA can be entrusted to enforce the mitigation measures used by the systems approach."

ACCORDINGLY, IT IS SO ORDERED that plaintiffs be granted summary judgment and defendants be denied summary judgment. IT IS FURTHER ORDERED that the Argentine citrus rule is suspended until a new rule is in place. The final rule is remanded to APHIS to address the concerns raised by the court."

Source: Harlan Land Co. v. USDA (2001).

Despite institutional confidence, domestic industry concerns led U.S. officials to be cautious in rule-making. Argentine officials eventually complained about unnecessary delays and APHIS published a final ruling on June 15, 2000, which allowed immediate entry (Magalhães, 2001; USDA APHIS, 2000). Regardless, opposition in the United States continued as growers questioned the ability of trade partner institutions to adequately monitor and carry-out the steps of the systems approach. Legislative representatives from California threatened APHIS with a withholding of fiscal year 2001 funding until after a review of the Argentine citrus rule and associated risk assessment were commissioned (NAWG, 2000; Costa, 2000).

To address grower concerns, APHIS personnel conducted an unannounced review in March 2001. Regulatory officials visited SENASA offices to verify the presence of sufficient technical personnel, examine agency records, and visit a laboratory. Throughout the review, APHIS did not discover any irregularities or violations and, despite strong continued opposition from California, lemon trade continued.

A Challenge to U.S. Institutions

On March 30, 2001, California and Arizona citrus growers filed a lawsuit directly challenging APHIS' scientific procedures and asking that the final rule be overturned (Harlan Land Co. v. USDA, 2001). Complainants argued that the final rule was unlawful because of its inconsistency with the Plant Quarantine Act of 1912. On May 12, 2001, arguments were heard in an Eastern District of California court. Institutional uncertainty surrounding both APHIS and SENASA was raised as prosecutors argued that the risk assessment was confusing and internally inconsistent. Further concerns were reliance on a foreign regulatory institution (SENASA) to implement, verify, and enforce part of the systems approach since, in the recent past, this institution had concealed an outbreak of foot-and-mouth disease for several months. The distrust of California growers for international regulatory officials had been extended to include domestic scientists and regulators. The court ruled in favor of the prosecution and entry of Argentine lemons was again banned as of September 29, 2001.

The Story Continues

With imports to the United States halted, Argentina announced in February 2002 that citrus canker had been detected in the Northwest states. Continued discussions between the two countries postponed an official APHIS site visit until the week of March 10, 2003. The goal was to demonstrate that, despite the loss of canker-free status, systems approach safeguards were rigorous enough to meet phytosanitary standards. This argument was not fundamentally different than that posited by Argentina in the 1990s. By 2003, however, the Argentine claim had been strengthened by additional scientific and institutional evidence. Based on results of the visit, APHIS formally recognized the appropriateness of the systems approach in place, but criticized the Argentine government for not implementing a canker eradication program (Wager-Page et al., 2003). Growers and policymakers in Argentina rejected the demand for such a program and the process remained stalled.

A new development in this story took place in January 10, 2006, when USDA officials declared defeat in their own canker eradication process announcing that Florida hurricanes had "so widely distributed [the disease] that eradication is infeasible" (Conner, 2006). There is a sense among Argentine officials that this announcement may induce APHIS to abandon the request for an eradication program in Northwest Argentina and instead develop a new protocol along the lines of the systems approach policies currently in place for Europe and Japan. In early 2006, a group of APHIS and SENASA officials met to further discuss the issue (Enright, 2006).

Lessons Learned

The Argentine lemon case reveals important lessons regarding trust and confidence among trade partners and the difficulties involved in decreasing institutional uncertainty. There is a demonstrated need for developing countries seeking access to international markets to organize and establish strategies based on scientific evidence and enforcement programs. Sanitary and phytosanitary policies based on multiple safeguards appear to be a valid tool to decrease regulatory uncertainty while achieving a reduction in pest risk, allowing trade partners to build mutual trust and confidence.

Phytosanitary measures must be consistently enforced over time by the exporting country to reduce distrust from the importing country; however, the regulatory agency in the exporting country is not the sole place where such uncertainty may arise. The dynamics of the lemon case shifted attention to credibility of domestic, as well as foreign, institutions. In this case, while trust and confidence between regulatory agencies has been slowly building, the same cannot be said for the industries involved. Although institutional and scientific adjustments in the developing country were crucial to build mutual trust and facilitate advancement of the regulatory process, some adjustments are still needed to overcome political pressures at home and abroad.

Acknowledgments

We would like to thank David Orden, Everett Peterson, and three anonymous reviewers for helpful comments and suggestions. This research was supported by the Program of Research on the Economics of Invasive Species Management (PREISM), Economic Research Service, U.S. Department of Agriculture, under Cooperative Agreement 43-3AEM-3-80087.

For More Information

Conner, C. (2006). *Letter to Charles H. Bronson, Florida Commissioner of Agriculture*. Available online: http://www.doacs.state.fl.us/pdf/Canker%20-%20Bronson.pdf.

Costa, J. (2000). *Importation of Argentine Citrus*. Bill Number: SJR 38. Adopted in Senate on August 31, 2000. Available online: http://info.sen.ca.gov/pub/99-00/bill/sen/sb_0001-0050/sjr_38_bill_20000920_chaptered.html.

Enright, C. (2006). *Letter to Carlos Horacio Casamiquela, Vice-President Servicio Nacional de Sanidad y Calidad Agroalimentaria (SENASA)*, January 27. Document retrieved from the Embassy of Argentina, Washington, DC, in March 2006.

Food and Veterinary Office [FVO]. (2002). *Final Report of a Mission Carried out in Argentina from 10-14 September 2001 in Order to Evaluate the Inspection Procedures for Citrus Fruit Originating in Argentina and Exported to the European Union*. European Commission - Directorate-General Health and Protection of the Consumers. DG (SANCO)/ 3403/2001 - MR FINAL. Available online: http://ec.europa.eu/food/fs/inspections/pi/reports/argentina/pi_rep_arge_3403-2001_en.pdf.

Harlan Land Co. v. USDA. (2001). *Court Ruling*. Eastern District of California. Factual Background. Available online: http://www.thecre.com/pdf/Citrus_vs_usda.pdf.

Magalhães, J. (2001). *Sanitary and phytosanitary issues and the SPS Agreement*. Presented at China/ FAO Citrus Symposium, Beijing, China. Available online: http://www.fao.org/DOCREP/003/X6732E/x6732e13.htm.

National Association of Wheat Growers [NAWG]. (2000). NAWG joins opposition to citrus limits. *NAWG newsletter*. Available online: http://www.smallgrains.org/dtnfiles/081100.htm.

Orden, D., & Romano, E. (1996). *The Avocado Dispute and Other Technical Barriers to Agricultural Trade Under NAFTA*. Presented at NAFTA and Agriculture: Is the Experiment Working? San Antonio, TX.

Roberts D. & Krissoff, B. (2004). *Regulatory Barriers in International Horticultural Markets*, (WRS-04-01). Washington D.C.: USDA Economic Research Service. Available online: http://www.ers.usda.gov/publications/WRS04/jan04/wrs0401/.

Thornsbury, S., & Romano, E. (2002). *Scientific Capacity and Institutional Adjustments for Standard Development*. Presented at Free Trade of the Americas, the WTO, and New Farm Legislation, San Antonio, TX.

United States Department of Agriculture [USDA APHIS]. (1998a). Importation of Grapefruit, Lemons, and Oranges from Argentina. Proposed Rule. *Federal Register 63*(155): 43117-43125.

United States Department of Agriculture [USDA APHIS]. (1998b). *Proposed Rule for Importation of Grapefruit, Lemons, and Oranges from Argentina, Environmental Assessment*. Available online: http://www.aphis.usda.gov/ppd/es/pdf%20files/argentea.pdf.

United States Department of Agriculture [USDA APHIS]. (2000). Importation of Grapefruit, Lemons, and Oranges from Argentina. Final Rule. *Federal Register 65*(116): 37608-37669.

United States Department of Agriculture [USDA APHIS]. (2002). *The Role and Application of the Systems Approach*. A Scientific Review coordinated by The National Plant Board. Available online: http://www.aphis.usda.gov/ppq/systemsapproach/.

United States Department of Agriculture [USDA FAS]. (2005). *FAS Guide to World Horticultural Foreign Agricultural Trade: U.S. Specialty Crops Trade Issues*. (Circular Series FHORT 1-05) Washington D.C.: Foreign Agricultural Service. Available online: http://www.ers.usda.gov/publications/WRS04/jan04/wrs0401/.

Wager-Page, S.,Van Dersal, J.M., Robertson, S., Demarino, Y., & Gaskalla R. (2003). *Trip Report. Site Review of Northwest Region Proposed for Citrus Exports from Argentina*. March 9-14. Document retrieved from the Embassy of Argentina, Washington, DC, in March 2006.

Eduardo Romano (romano@pire.org) is Associate Research Scientist, Pacific Institute for Research and Evaluation (PIRE), Calverton, MD. Suzanne Thornsbury (thornsbu@msu.edu) is Assistant Professor, Department of Agricultural Economics, Michigan State University, East Lansing, MI. Senior authorship is shared.

CHOICES
3rd Quarter 2006 • 21(3)
The magazine of food, farm, and resource issues
A publication of the American Agricultural Economics Association

Invasive Species and the Depth of Bioeconomic Integration

David Finnoff, Chad Settle, Jason F. Shogren, and John Tschirhart

JEL Classification: Q0

An established species is not considered invasive unless it triggers costs that outweigh any attendant benefits. Numbers of invasive species are increasing worldwide. In the United States alone, Pimentel et al. (2000) estimated that 50,000 non-native species have been introduced. Of these about 5,000 have become established and about 500 have become invasive.

Invasive species are a leading cause of biodiversity loss in ecosystems, and especially in lakes. Invasive species promote large ecosystem changes, and they interact with many other drivers of global environmental change. Although agriculture has been long plagued by invasives and a voluminous literature on cost effective pest control exists, only relatively recently has the problem of invasives in natural systems been examined in a bioeconomic context.

In the past, researchers have used an approach that assumes the economic system and the ecosystem affect each other in a one-sided way, which causes them to separate risk assessment from risk management. A change in the economic system is viewed as only changing the pressure on the ecosystem, or a change in the ecosystem is viewed as only changing the economic system. This approach does not address the idea of *co-evolution* – the two-way interactions and feedbacks between human and natural systems. Ecosystem changes alter human behavior and productivity in the economic system. People recognize the change in their productivity, and they adapt to this change, either by adapting the environment or by adapting to the environment. When people adapt, they alter the pressure they put on the ecosystem leading to further changes in the ecosystem. The co-evolutionary cycle continues.

Co-evolution can be addressed by integrating ecological and economic modeling into a single cohesive framework. The motivation behind integration is to get more precise estimates of invasive species damages on human and natural systems. Integration accounts for interdependencies, or *feedback loops*. Traditionally, economists have captured the notion of feedback loops using dynamic models. With a few exceptions, most standard bioeconomic models consider at most one or two feedback loops and operate at a relatively aggregate level. In many cases such models provide the needed insight into the underlying problem at hand. In other cases, however, more ecological or economic detail is needed to help avoid the unintended consequences of poorly advised policy. This challenge of balancing model tractability with more realism is not new in science, but it hits with full force when addressing the economics of invasive species management.

Herein we address two common questions that arise when doing integrated bioeconomic modeling for invasive species management: (1) what do we gain by integrating the web of life into economic analysis? and (2) if integration is worthwhile, how deep should we go?

What do we gain by integrating the web of life into economic analyses?

Our work over the last decade has addressed whether an explicit accounting of these feedback links yields different policy-relevant results than does non-linked analyses. Consider three examples of linked systems.

i. Yellowstone Lake

Settle and Shogren (2006) constructed an integrated bioeconomic model to examine how invasive lake trout affect native cutthroat trout in Yellowstone Lake. The two key items included in this model are the stocks of lake trout and cutthroat trout. Their results showed how integration of the economic and biological systems lead to different population results compared to treating the systems as separate. Three scenarios were considered, each with and without feedbacks between the economic and ecological systems. The best-case scenario eliminates lake trout immediately and without cost. The worst-case scenario leaves lake trout without any interference from the Park Service, and both lake and cutthroat trout are left to reach their steady-state equilibriums. The middle-ground scenario has the Park Service expending a fixed budget to reduce the risk to cutthroat trout by gill netting lake trout, assuming the Service's current level of expenditures is continuous and perpetual.

Using the population of cutthroat trout as a yardstick, we found that ignoring feedbacks biases risk estimates by overestimating cutthroat populations in the worst case and underestimating them in the best case. The difference arises from fishermen behavior. Without feedback, fishermen continue to fish as before. With feedback, fishermen adapt by fishing less and visiting other attractions more. Interestingly, the findings also revealed a troubling result from a species protection perspective in that only a small difference arises between the net benefits between the best- and worst-case scenarios, which suggests that gill netting for lake trout is inefficient. People preferred improvements in other park amenities (e.g., roads, wildlife viewing) relative to increased populations of cutthroat trout.

ii. Zebra mussels

Finnoff et al. (2005) studied an economic system, composed of a Midwest lake ecological system experiencing a zebra mussel invasion with a resource manager and a powerplant, to determine whether integrating the systems is worth the effort. Two feedbacks were considered—one between the biological system and power plants based on the stock of zebra mussels, and one between the power plants and the manager based on the manager's expectations over the plant behavior. For both loops, the decision maker's beliefs about invasions are central. In the absence of the link between the biological system and power plants, a plant behaves as if its actions cause no change in the biological system. The consequences depend on whether there is an invasion in the initial period, and whether the power plant acknowledges the presence of the invader. For example, with no initial invasion, the power plant neither controls nor adapts, and as the biological system changes, the power plant either uses too few or too many inputs relative to the optimal baseline. In turn, output correspondingly either under- or over-shoots its targeted level; either way this results in opportunity cost losses from production shortages or surplus, determined ex-post.

The second dimension is the feedback between the resource manager and power plant. Removing the feedback causes the manager to act as if the power plant does not respond to changes. For example, following a successful invasion, the manager ignores the private control actions of the power plant. This has direct welfare consequences as resources may not be allocated efficiently, but the magnitude of the consequence depends on the actual response of the power plant. The results suggest that feedbacks can matter for this case—but not in every dimension and in varying degrees. Both biological and economic consequences of not addressing feedbacks are sensitive to the initial environment, behavioral perceptions about the state of the environment, and the completeness of the manager's beliefs.

iii. Leafy spurge

Finnoff et al. (2006) developed an integrated model of a grazing land ecosystem and cattle ranching. The ecosystem consists of native grasses, leafy spurge (an invader noxious to cattle and wildlife), and cheatgrass (another invader). This model considers the stocks of each plant and cattle. Plants in these three species are assumed to behave as if they are maximizing their photosynthetic energy intake minus energy lost to respiration. To photosynthesize, they grow green biomass that provides them access to light; however, the plants are competitors for space. Over time one species eventually will win the competition by driving out the other two.

The results show that without humans, the native grasses are most likely to win. When humans enter and introduce cattle to the grazing ecosystem, the native grasses are placed at a competitive disadvantage, and leafy spurge generally becomes dominant depending on grazing intensity. The model illustrates the importance of accounting for grazing decisions when forecasting the further spread of leafy spurge.

If integration is worthwhile, how deep should it go?

Integrating ecological detail into economic models raises many issues on different levels. The fundamental issue is deciding how deep the integration should go within and between the economic and ecological systems. The tradition in economics

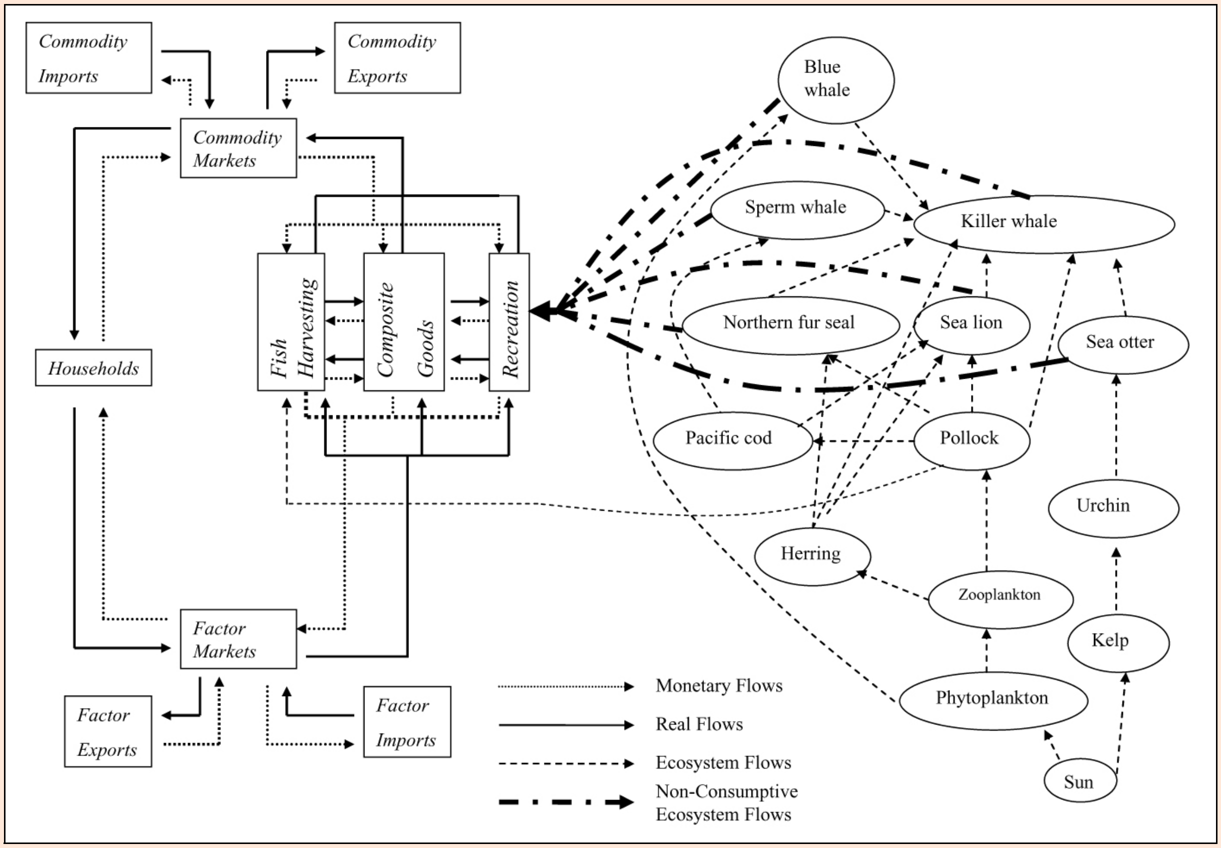

Figure 1. Bering Sea web of life.

is to represent ecological systems as a technical constraint, usually in the form of population growth for a single or aggregate species. The influence of all other species and other components of the ecological system are represented by a fixed carrying capacity. If the policies prescribed by these models do not impact other components of the ecological system, this representation may be appropriate. But if the policies do impact other components of the ecological system, the system can be "bumped" to different results with unintended consequences (Crocker & Tschirhart, 1992). Models not addressing these other components may miss important linkages between humans and nature and provide misguided policy prescriptions.

Deciding just how deep to dig within and between the economic and ecological systems depends on the number of contact points between the systems and the indirect effects within the systems. For cases with one or two points of contact, a *shallow*, or abridged form of integration might suffice. But in cases with multiple contacts or important indirect effects, a *deep* integration is necessary. But in doing so it is necessary to make other simplifying assumptions. Such deeply integrated models may not be more realistic if the feedback loop or other representations do not conform accurately to reality. Addressing the challenge of adding more realism and being forced to solve a problem computationally rather than analytically requires one to work with a solid theoretical framework that guides the depth of integration.

We illustrate the depth of integration challenge by using an example based on Finnoff and Tschirhart (2005) that examines the Alaskan economy and a marine ecosystem comprising Alaska's Aleutian Islands (AI) and the Eastern Bering Sea (EBS). Figure 1 shows the ecosystem and economic interactions and illustrates the thirteen key ecological descriptors and the feedback loops. The economy consists of Alaskan households and producing sectors linked to one another and the rest of the world through commodity and factor markets. All species in the food web are linked through predator-prey relationships and several species provide inputs to economic production. The prominent groundfish of the system, pollock, support a substantial fishery, and marine mammals including Steller sea lions (an endangered species), killer whales, blue whales, sperm whales, northern fur seals and sea otters. All of these species provide non-use inputs to the state's recreation sector. For a policy issue, we focus on the endangered Steller sea lion recovery via alternative pollock harvest quotas.

The first level of analysis is to understand the behavior of the actors in Figure 1. Economists study the behavior of individual consumers and producers. Consumer behavior has people within the household sector box making choices over combinations of goods and services. In Figure 1 this is a focus. Producer behavior is likewise captured by individual firms within the fish harvesting sector box choosing both their optimal mix of inputs and their optimal output level. Alternative quota levels are interpreted as changes in the prices faced by the households or producers. Similarly, ecologists study the behavior of individual animals; they would consider an individual pollock's optimal foraging behavior, and how foraging changes impact pollock populations as depicted within the pollock box. The alternative quotas would be interpreted as changes in the pollock populations.

The next level of analysis is to integrate all economic and ecological agents directly affected by pollock quotas through a bioeconomic harvesting model. In the economic system, individual consumer demands for pollock are aggregated to derive market demand, required for producers' decisions. Producer supplies are in part determined by the availability of pollock, which is derived from the aggregation of individual pollock behavior and population dynamics. Therefore, this level requires integration *across* the household, fish harvester, and pollock components. Linking these three components allows the derivation of market demand and pollock supply, which allows an assessment of how alternative quota policies impact the whole system.

But this level of integration is insufficient if we are interested in how the repercussions of the policies impact all of Alaska. In this case, deepening the analysis a further step *within* the economic system is necessary to include the other producing sectors of the Alaskan economy (recreation and composite goods in Figure 1), all other household demands, and trade flows into and out of the region. A complication arises, however, because the recreation industry depends on the marine mammals. Still further depth of integration is needed *to* increase depth *within* the ecosystem to account for the predator-prey relationship shown in Figure 1.

Finally, another level of integration is needed with nonmarket valuation. Nonmarket valuation involves assessing the total values (e.g., existence values) associated with scenarios of reduced human and environmental damages posed by some invasive species so we can better understand the net benefits of policy. The idea is that valuation work needs integration models to develop credible valuation scenarios. In turn, integration models need the parameters as defined by valuation work to capture the full range of benefits associated with the web of life. For instance, in the Yellowstone Lake case, Settle and Shogren (2006) integrated a valuation experiment within their bioeconomic model. They developed the *Yellowstone Interactive Survey* to ask people to value alternative scenarios designed to inform their integrated model. They determined the value for seeing/catching each species and used these estimates to parameterize the value to see/catch each species in measuring the visitor's welfare from Yellowstone National Park. The disquieting result that people preferred fixing the roads to protecting the native cutthroat trout emerged directly from this integration. Both valuation and bioeconomic modeling can likely be more relevant for policy if the scenarios people are asked to value are valid and if the scenarios created were informed by values stated by actual people. There are gains from joint production of values and feedback loops between economic and ecological systems.

Concluding Comments

Over the years, traditional bioeconomic modeling has improved environmental and natural resource decision making. Today researchers are exploring the next level of integration by expanding the number of feedback loops within and between systems and by making a better link to nonmarket valuation work. This message applies in general to natural resource economics and in particular to invasive species economics. The open question is how to determine the appropriate level of integration for the problem at hand? Is a traditional damage function approach sufficient? Does a one or two state variable optimal control model provide enough guidance, or do we require an even deeper integration between and within disciplines that may only be solved computationally? Addressing these questions requires one to judge a method based on results, not by preconceived methodological principles. Our decisions on the depth of integration in invasive species economics should evolve from our experience about what works and what does not work.

For More Information

Brock, W., & Xepapadeas, A. (2002). Optimal ecosystem management when species compete for limiting resources. *Journal of Environmental Economics and Management*, *44,* 189-220.

Crocker, T., & Tschirhart, T. (1992). Ecosystems, externalities, and economies, *Environmental and Resource Economics, 2,* 551-567.

Finnoff, D., Shogren, J.F., Leung, B., & Lodge, D. (2005). The importance of bioeconomic feedback in invasive species management. *Ecological Economics, 52,* 367-381.

Finnoff, D., & Tschirhart, J. (2005). Linking dynamic economic and ecological general equilibrium models. *Working Paper,* University of Wyoming.

Finnoff, D., Strong, A., & Tschirhart, J. (2006). Preventing the spread of multiple herbaceous invaders across rangeland. *Working Paper,* University of Wyoming.

Perrings, C., & Williamson, M., eds. (2000). *The Economics of Biological Invasions*. Northampton, MA: Edward Elgar Publishing, Inc.

Pimentel, D., Lach, L., Zuniga. R., & Morrison, D. (2000). Environmental and economic costs of non-indigenous species in the U.S. Paper. *BioScience, 50,* 53-67.

Settle, C. & Shogren, J. (2006). Does the integration of biology and economics matter for policy? The case of Yellowstone Lake. *Topics in Economic Analysis and Policy 6*(1), Article 9. Available online: http://www.bepress.com/bejeap/topics/vol6/iss1/art9.

David Finnoff (finnoff@uwyo.edu) is Assistant Professor, Department of Economics and Finance, University of Wyoming, Laramie, WY. Chad Settle (chad-settle@utulsa.edu) is Associate Professor, Department of Economics, University of Tulsa, Tulsa, OK. Jason Shogren (jramses@uwyo.edu) is the Stroock Distinguished Professor and John Tschirhart (jtsch@uwyo.edu) is Professor, both at the University of Wyoming, Laramie, WY.

The authors thank the Economic Research Service (USDA), National Science Foundation, and the Environmental Protection Agency for funding support.