Science and Economics in the Management of an Invasive Species

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*Estimates of the economic impacts of nonnative nuisance ("invasive") species must rely on both a sound ecological understanding and the proper application of economic methods. Focusing on the example of the invasive European green crab (*Carcinus maenas*), we show that the crab's estimated economic impact—which has been used to help justify recent public policy—is based on data taken from the wrong geographic location. Furthermore, the predictions of ecological effects appear to rest on loose footing, and economic methods have been misapplied in constructing the estimate. Our purpose is to call attention to the need for the more careful application of science and economics in managing this pressing environmental issue.*

Keywords: invasive species, European green crab, ecological effects, economic impacts, public policy

The accidental introduction of nonnative nuisance ("invasive") species is a critical environmental issue. Estimates of the economic damages arising from these introductions are needed to formulate effective policy in this area. Damage estimates can help policymakers and managers to understand the gravity of the problem and develop appropriate management responses. To be useful, such estimates must rely on both a sound ecological understanding and the proper application of economic methods.

To date, policy responses to the introduction and spread of invasive species have been based on very crude estimates of economic damages. For example, in drafting the Ballast Water Management Act of 2005 (S. 363), the US Senate found that annual estimates of the costs to the US economy from aquatic nuisance species alone range from millions to billions of dollars. This finding can be traced back to a compilation by Pimentel and coauthors (2000, 2005) of the annual economic effects of many of the invasive species that have become established in the United States. There are many reasons to be concerned about the use of these estimates for policymaking, however.

The European green crab

To illustrate our point, we focus on one particular species, the European green (or shore) crab (*Carcinus maenas*). In the United States, the green crab has gained a reputation, perhaps undeservedly, as a ravenous predator that can lay waste to shellfish stocks (Hedgpeth 1993). The green crab is native to the Atlantic coast of Europe, and it is thought to have been introduced along the US Atlantic coast in the early 19th century. By the mid-20th century, the crab had spread northward from Cape Cod along the coasts of Maine and Nova Scotia. By 1990, it had appeared in San Francisco Bay, and thereafter it began to expand its range into estuarine environments northward along the West Coast.

The estimate by Pimentel and colleagues (2000, 2005) of the annual economic costs of the green crab invasion into New England is $44 million. Pimentel and colleagues cite Lafferty and Kuris (1996) as the source for their estimate.

To support their argument for the potential impacts of the green crab on the West Coast, Lafferty and Kuris examine several early studies from the 1950s (Glude 1955, MacPhail et al. 1955, Moulton and Gustafson 1956) and two later studies (Ropes 1968, Elner 1981) of the likely adverse effects of the green crab in New England coastal waters. They state that these studies find the green crab is "associated with" the demise of the softshell clam fishery in northern New England and Nova

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Scotia. Lafferty and Kuris argue that the possibility exists for economic losses of all or part of the landings of the Dungeness crab, rock crab, mussel, oyster, and bait fisheries in northern and southern California and in Washington State's Puget Sound.

In fact, Lafferty and Kuris estimate the potential, not the actual, impacts of the green crab; and their estimates are for California and Washington State, not for New England (see also Carlton 2001). The number that Pimentel and colleagues (2000, 2005) cite as reflecting the economic impact of the green crab in New England is actually Lafferty and Kuris's estimate of the crab's *potential* impact only in Puget Sound.

Uncertain ecological impacts

The predictions Lafferty and Kuris (1996) made about ecological effects may rest on loose footing. For example, in northern California, where green crabs had been established by the time of their paper's publication, Lafferty and Kuris attributed about 90 percent of the crabs' potential economic impact to the complete loss of harvests in the Dungeness crab fishery. A reasonable interpretation of the data on Dungeness crab landings, however, suggests that the green crab has not yet had any discernible effect on this fishery (figure 1a; CDFG 2005).

Pimentel and colleagues (2000, 2005) and Lafferty and Kuris (1996) base their arguments for the green crab's economic impacts on assumed losses in the New England softshell clam (*Mya arenaria*) fishery, which is concentrated in Maine. However, neither set of authors appears to have examined the status of this fishery in the period since the 1950s, when the first studies suggested a link between the green crab and the possible demise of the softshell clam. Data on landings of softshell clams in Maine (figure 1b) suggest that the demise of the state's softshell clam fisheries may have been overstated (figure 1b; MDMR 2005). What is clear is that the explanation for changes in softshell clam yields, on which the argument for impacts from the green crab relies, may be more complicated than a simple story about one predator and one prey (Welch 1968, Gillis et al. 2000, Yamada 2001).

Misapplications of economic methods

The estimate made by Lafferty and Kuris (1996) of the potential economic impact of the green crab on West Coast shellfisheries is a misapplication of economic methods in several respects. A correct measure of damages associated with aquatic nuisance species should be based on a comparison of invasion scenarios before and after an invasion. Lafferty and Kuris take the ex-vessel value of landings in selected West Coast fisheries during 1990 and 1991 as the beginning datum. They develop two economic impact metrics from this value: lost "net revenues" and lost "secondary and tertiary values." They assume afterward that the value of ex-vessel revenues is completely lost in each of the fisheries. Why that assumption seems unrealistic has already been covered. Here the discussion turns to the implications of their choices of metrics.

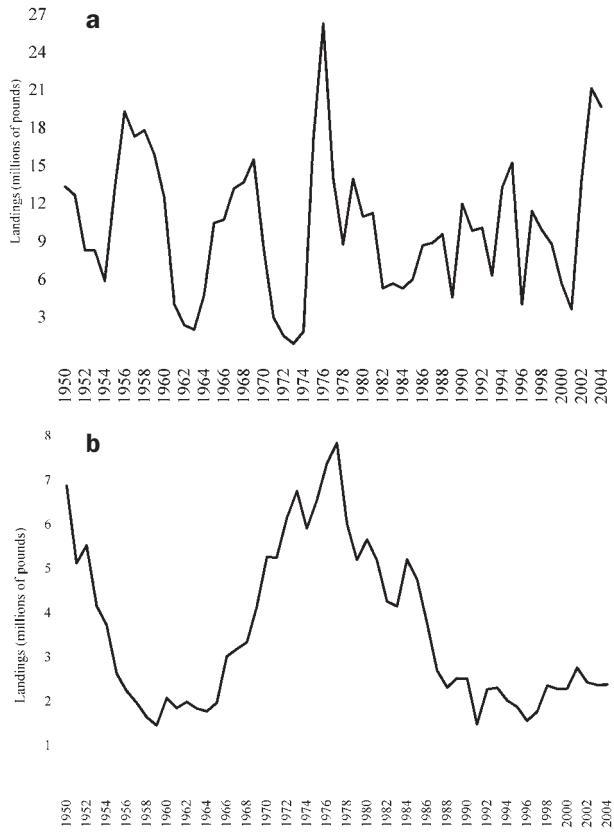

Figure 1. Fifty-four years of (a) Dungeness crab landings in northern California, including the Crescent City–Eureka–Fort Bragg, Bodega Bay–San Francisco, and Monterey Bay–Morro Bay areas (CDFG 2005), and (b) softshell clam landings in the state of Maine (MDMR 2005).

The estimate of the potential economic impact of the green crab on West Coast shellfisheries is inconsistent with economic theory in at least two ways. First, Lafferty and Kuris attempt to estimate the "net" revenues from West Coast shellfisheries. A calculation of the net revenues lost to a fishery would be an appropriate, albeit possibly incomplete, measure of the costs to the economy from predation by the green crab. The total loss to the economy should be the sum of declines in both consumer and producer surpluses. If there are close substitutes for the species in question, it is not unreasonable to assume that consumer surplus changes might be small. The institutional measures used to manage the relevant fisheries, however, may dictate whether changes in producer surpluses (or net revenues) are small or large (Freeman 1991). If the fishery is not managed rationally (i.e., with taxes or transferable quotas), it would be unrealistic to expect net revenues to be significant, except possibly during an unusually productive fishing season.

Unfortunately, Lafferty and Kuris's estimate of lost net revenues is unrealistic. The authors adjust gross revenues for the relevant fisheries down by 20 percent to account for the costs of fishing, yielding an estimate of net revenues that is 80

percent of gross revenues. They do not explain their justification for selecting the scale of this adjustment. Even though the Dungeness crab fishery is a limited-access fishery, it would be unusual for any industry to operate with an 80 percent profit margin.

The management measures applied in the California Dungeness crab fishery (limited access, closed season, gear restrictions, and size and sex restrictions) suggest that fishing costs cut substantially into resource rents. Dewees and colleagues (2004) explain that the fishery has been "fully and intensely" exploited for at least 40 years. Although there is a moratorium on entry in this fishery, regulations do not limit fishing effort because fishery participants are not restricted in their application of time, number of traps, vessel size, or horsepower. As a consequence, there is a race for fish, and most landings occur during only the first six weeks of a seven-month season. Although we are unaware of any published analysis of rents for this fishery, an estimate of the scale of fishery rents, based on the results of the 2002 survey of capitalized crab permit values conducted by Dewees and colleagues (2004), suggests that they are approximately only 3 percent of gross revenues (about $564,413 on ex-vessel landings of $17.72 million during the 2000–2001 season, using a discount rate of 5 percent). Consequently, the use of net revenues as calculated by Lafferty and Kuris probably overstates by an order of magnitude the loss to the fishery, even if reductions in landings had been both observed and linked conclusively to green crab predation of Dungeness crab juveniles.

Second, Lafferty and Kuris apply a multiplier of 1.5 to net revenues in order to capture the direct, indirect, and induced effects on the economy of the loss of revenues from these fisheries (what the authors refer to as secondary and tertiary values). The authors neither justify their selection of a multiplier of 1.5 nor specify the type of multiplier (cf. Leung and Pooley 2002). Although the authors do not identify the origin of their multiplier, it seems likely that they chose it from the results of a calibrated regional economic input–output model. Even in that case, however, the resulting estimate would not be a valid measure of economic loss in a fishery. The reason is that this particular economic impact measure includes the *costs* of business activities. If the landings fall to zero and these activities are discontinued, the costs of fishing for these species and the costs in linked industries would not be incurred. Further, the resources used for fishing and the industries to which it is linked would soon be redistributed to their next best productive uses in the economy. Consequently, these impact estimates may also overstate actual losses to the economy.

An economic approach

An economic approach consists of estimating in monetary terms the actual or potential economic damages resulting from an invasion and the costs associated with alternative management responses, including the possibilities of preventing the invasion, controlling its spread, eradicating the invader, or doing nothing at all. Damages are then compared with response costs in order to suggest an appropriate policy. An economically optimal policy is one that minimizes the combined sum of damages and control costs.

A correct measure of invasive species damage to a fishery must be based on a comparison of economic value before and after an invasion. A description of economic value after an invasion may be hypothetical, but it must be realistic and based on sound ecological understanding. Without this understanding, there is a significant risk that management actions will be wasteful or feckless. Damages to a commercial fishery should include lost consumer and producer surpluses; in many situations, net revenues may be an appropriate measure of damages. Estimates of changes to economic surpluses can be derived from a model of supply and demand in the relevant market; often such models require an understanding of the biological dynamics and ecological interactions relating to the exploited stocks (Conrad and Clark 1987).

There also may be changes in the flow of nonmarket ecological services when an ecosystem is modified by an invasion. These damages may lead to lost recreational opportunities and so-called passive-use damages, which involve the possibility of economic losses in the absence of direct physical uses of an ecosystem (Freeman 1995). Nonmarket damages often are difficult to quantify because of the complex interactions among species in an ecosystem, the uncertain outcomes of these interactions, the lack of information about the public's preferences across alternative ecological states, and the methodological difficulties in measuring those preferences. Only a few studies have begun to provide estimates of nonmarket damages from invasive species (Lupi et al. 2003, Nunes and van den Bergh 2004).

Where invasive species have been introduced by humans, whether intentionally or not, the resource economics literature treats invasive species properly as a form of biological pollution (Horan et al. 2002). Like other forms of pollution, the unintentional introduction of nuisance species is a byproduct of normal economic activities, such as shipping, aquaculture, or marine recreation. A standard theoretical result is that nuisance species should be controlled until the last dollar invested in control yields an equivalent amount in damage reduction. Because the interactions between economic and ecological systems often are complex (Settle et al. 2002), most economic studies focus appropriately on the effects occurring only in the relevant markets, thereby ignoring the consequences for the rest of the economy. One supporting assumption in such "partial equilibrium" studies is that the effects on the broader economy are negligible.

Options for controlling invasive species may involve prevention, culling, or eradication. Although public policy appears to favor the prevention of introductions (e.g., through ballast water regulations), prevention is not necessarily economically efficient in all circumstances. Whether prevention is efficient may depend on the expected economic damages relative to prevention costs, the effectiveness of preventive actions, and the discount rate (Jensen 2002). Once an invasion has occurred, control costs may be a function of the size of

the invading population. As in the case of a fishery, the marginal costs of control typically decline with increased numbers. Consequently, for some invasions, it may be economically efficient to allow the population of an invader to grow until the marginal culling costs have been lowered sufficiently (Olson and Roy 2003). Finally, an economically optimal policy should lead to a reduction in the rate of invasion or in the spread of a particular species, but it does not necessarily involve the eradication of an invader (Olson and Roy 2002, Skonhoft and Schulz 2003). Eradication policies often involve control costs that mount at an increasing rate, so that the benefits (in terms of reduced losses) become small in relation to control costs.

An ideal model of aquatic nuisance species management also comprises dynamic and multispecies aspects, because biological invasions occur over time and involve multifaceted ecological interactions. For example, Barbier (2001) develops a predator–prey model that captures interspecific competition and dispersion. Barbier's model shows that the extent to which the profits from commercial fishing are reduced by the introduction and spread of an invasive species depends critically on the type of ecological interaction that exists. This result can be generalized to the other dimensions of an ecological system, implying that the scale and time distribution of economic damages may be sensitive to changes in intrinsic growth rates, carrying capacities, or other relevant biological parameters.

Knowler and colleagues (2002) apply these concepts to the interactions between nutrient enrichment, an invasive species, and fisheries in the Black Sea. The authors assume that recruitment to stocks of Black Sea anchovies is related positively to nutrient levels. When an exotic comb jelly is introduced, however, nutrient enrichment leads to a "regime shift" in which recruitment to anchovy stocks is diminished and the comb jelly flourishes. The authors show how to estimate the scale of economic benefits associated with controls on nutrient releases that could prevent the regime shift.

Barbier (2001) has suggested that future modeling efforts should consider more complex ecological interactions (e.g., between invading and resident species), modifications to natural habitat, and nonmarket damages. Settle and Shogren (2002), for example, develop a model in which visitors to Yellowstone National Park benefit from harvests of either a native fish (cutthroat trout) or an invasive fish (lake trout) and from sightings of either birds of prey or grizzly bears. Species flows in the model depend on ecological interactions (humans, birds of prey, grizzlies, and lake trout are all predators of cutthroat trout). Park managers must choose to divide a limited budget between culling lake trout and improving access roads in order to maximize economic benefits to park visitors.

From a pragmatic perspective, the analytical complexity of theoretical models—and the length of time needed to put them into practice—often represents a severe constraint to implementing management responses in real time. Consequently, there is a need to simplify modeling approaches to avoid analytical paralysis. Leung and colleagues (2005) develop a framework for rapid assessments to guide investments in prevention or control. In their framework, ecological complexity is simplified to a relatively small number of easily estimated parameters.

Biological invasions frequently are unexpected, novel events (Perrings et al. 2002). They may lead to catastrophic and irreversible consequences, and they may involve unknown probabilities. Management decisions must be made on the basis of incomplete information about the set of possible invaders, the likelihood of their being introduced and spreading, and the potential economic damages when invasions occur. A general strategy for characterizing the risks associated with invasions requires an understanding of the temporal, spatial, and taxonomic completeness of ecological data and estimates of the potential distribution, abundance, and spreading rates of the invaders (Stohlgren and Schnase 2006).

Where probabilities about biological invasions are thought to be small but cannot be estimated easily (i.e., substantial uncertainty exists), the public might weigh outcomes involving extensive losses more heavily than if the risks were better known. In such instances, there is a strong tendency for the expected benefits of control to be highly valued (Horan et al. 2002). In other words, such conditions could lead to unnecessarily excessive levels of control. Studies that "assume the worst" are likely to contribute to this tendency, resulting in the implementation of economically wasteful policies. This conclusion reinforces the need for scientific research that helps to resolve the uncertainty.

Broader implications

The confusion over estimates of the economic impacts of the green crab has broader implications for policy development. Heretofore, estimates of the economic losses arising from invasive species have been far too casual. Unfounded calculations of economic damages lacking a solid demonstration of ecological effects are misleading and wasteful. Where hypotheses of adverse ecological effects cannot be rejected, a critical next step is the proper application of economic theory and methods to develop reliable estimates of economic losses. Such estimates can provide a foundation for sound public policy.

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