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Review

Review of harvest incentives to control invasive species

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Abstract

From nutria to lionfish, recent interest has grown in ways to encourage the harvest and use species as a means of controlling or eradicating invasive populations. If used properly, incentivizing and encouraging public or commercial harvest represents a significant opportunity to support ecosystem and natural resource management while simultaneously boosting economic development and environmental awareness. However, if used incorrectly, negative consequences such as further spread can occur. Success depends on interactions between the species, its invasive range, and socioeconomic factors, yet little guidance is available on how to use incentivized harvest as an effective management tool. This paper reviews the biological, ecological, human health, and socioeconomic factors involved in invasive species incentive programs. We also offer recommendations to assist in development and implementation of a successful harvest program.

Key words: biological invasions, pest, nuisance species, ecological management, control, incentives, harvest

Introduction

Invasive species are estimated to cause the United States tens of billions of dollars in environmental and economic damage each year (Pimentel et al. 2005). Management of these non-native species is necessary to protect native species and ecosystems, economic values, and human health; however, effective prevention, containment, and control activities often require financial resources and time that are not always available. Recently, incentive programs designed to promote harvest of invasive species populations as a management tool have received significant attention (e.g., Matsumoto 2013). Examples of programs that may use incentives to encourage the harvest of invasive species include:

Bounty Program – A financial incentive program in which a predetermined amount of money is paid to an individual upon satisfactory evidence of collection of a specified organism.

Contract Operation – A program that provides direct payment to the public or service provider to remove or harvest a species.

Commercial Market – An effort that is undertaken, usually privately, when a perceived market exists for a species and it can be harvested and offered for sale.

Recreational Harvest – Actions that enhance or encourage recreational fishing, hunting, or trapping of invasive species such as conducting outreach, modifying seasons, or changing license requirements or bag limits.

The potential for incentive programs directed at invasive species remains uncertain as few studies have critically examined the success of these programs; however, efforts to develop and implement harvest or other incentive-based programs have already begun. For example, commercial harvesting was identified as one of several strategies in the 2012 Asian Carp Control Strategy Framework to reduce the populations of invasive carp (particularly black carp (*Mylopharyngodon piceus* Richardson, 1846), bighead carp (*Hypophthalmichthys nobilis* Richardson, 1845), and silver carp (*H. molitrix* Valenciennes, 1844)) within the Mississippi River Basin (ACRCC 2012). Private industry has also been actively developing products

and markets that utilize Asian carp. For example, the Silverfin Marketing Group, created by Chef Philippe Parola, was created to eliminate the negative perception of Asian carp and promote it as a quality food item in domestic and international food markets (Asian Carp Solution 2012). In another instance, the State of Illinois' *Target Hunger Now* campaign encourages hunters and anglers to donate invasive carp and other nuisance animals which are later processed to feed thousands of needy families each year (IDNR 2012).

Adhering to the "If you cannot beat them, eat them" perspective, utilization of several other invasive species are also being promoted. For example, in 2010 the National Oceanic and Atmospheric Administration (NOAA) launched an *Eat Lionfish* campaign to bring together fishing communities, wholesalers, and chefs to broaden U.S. consumer awareness of the invasive fish (NOAA 2010). The International Coral Reef Initiative has also recommended harvest and tournaments as possible strategies to control lionfish in the wider Caribbean (Lozano et al. 2013).

Incentivized harvest programs also focus on terrestrial invasive species. 2013 marked the first year of the Florida Fish and Wildlife Conservation Commission's Python Challenge, an event to raise public awareness about the threats that non-native Burmese pythons (*Python molurus bivittatus* Kuhl, 1820) pose to the Everglades ecosystem and native wildlife (FWC 2013a). This month long harvest offered monetary awards to those who collected the longest and most pythons. Invasive plants also offer harvest opportunities. Kudzu (*Pueraria lobata* Ohwii, 1947), also known as "the plant that ate the South," is being evaluated for its potential as a biofuel crop. Kudzu could produce 2.2 to 5.3 tons of carbohydrate per acre, or about 270 gallons of ethanol per acre, representing a significant contribution to the U.S. bioethanol supply (Sage et al. 2009).

The above examples illustrate that there is a rising interest in combating invaders using commercial markets and other incentives. Given the apparent ease and low cost of running such programs, commercial utilization and harvesting seem to offer unique and potentially cost-efficient ways to reduce invasive species populations. Some programs have demonstrated success in reducing numbers of non-native species, suggesting that financial incentives have the potential to reduce, or even eradicate, invasive species populations under certain circumstances (Choquenot et al. 1998). However, incentive programs are not always successful and may result in wasted resources if populations fail to decline. If applied without careful consideration, as with any resource management tool, such programs can be damaging, costly, and produce a poor return on investment (Nuñez et al. 2012; Hassall and Associates 1998; Bartel and Brunson 2003). Currently, guidance and recommendations are lacking on how to use harvest as an effective tool for invasive species management. In one notable exception, the Mississippi River Basin Panel on Aquatic Nuisance Species (MRBP) developed draft policies for the commercial harvesting of aquatic invasive species. Their draft recommendations include euthanizing invasives immediately upon harvest, labeling species appropriately, requiring data submission, regulating harvest locations and seasons, requiring decontamination of equipment used, maintaining flexibility, and openly communicating objectives (MRBP 2007). In this paper we build upon previous considerations, including those from the MRBP, and evaluate the biological, ecological, human health, and socio-economic factors involved in invasive species incentive programs. We end with recommendations for developing and implementing a successful harvest program.

Biological considerations

Population dynamics

Some of the United States' most destructive species, such as sea lamprey (*Petromyzon marinus* Linnaeus, 1758), have been harvested to low levels in their native range (Renaud 1997); accordingly, commercial markets and other incentive programs appear to offer a promising solution to the country's invasive species problem. Deciding if an incentive program is an appropriate form of invasive species management requires understanding the population dynamics of the targeted species, this includes the species' density dependent processes, demographic structure, and specific vital rates. Invasive species exhibit distinct life history traits that aid their ability to thrive in new habitats. These characteristics include rapid growth, high fecundity, an ability to tolerate a wide range of habitat conditions and aggressively compete for resources, and a lack of natural predators. Consequently, the principles applied to managing game or endangered species may not be directly applicable to invasive species control. Understanding the population dynamics and life cycle of the target species is the foundation for successful invasive species management.

Familiarity with the population dynamics of the target species is necessary to calculate the

number of individuals that must be removed before a reduction in the population can be observed. If used as the sole form of invasive species control, incentive programs can only be effective if the number of individuals harvested exceeds the number that would normally not survive during a single breeding cycle. This may require high removal rates. For example, models have predicted that annual removal rates between 15 and 65% are required to reduce lionfish populations (Barbour et al. 2011), though targeted and repeated lionfish removals may be a viable management option to protect ecologically important species (Frazer et al. 2012). Removal efforts may be further confounded as efforts that target specific life history stages may not succeed. Many incentive programs, particularly for terrestrial species, often harvest younger, more naive animals, yet juveniles of invasive species may have a natural mortality of 50% or more (Hassall and Associates 1998). Alternatively, a study of the commercial harvest of Asian carp reported that efforts focused solely on larger-sized fish would decrease the likelihood of effective population control (Garvey et al. 2012; Tsehaye et al. 2013). Since smaller size classes are not as desirable in the food markets, new markets outside the food industry will be required. While a reduction in numbers of the population is desirable, removing specified life history stages, such as larger and more mature individuals, may still have a positive benefit on the ecosystem. These benefits may include a reduction in negative impacts from a reduced average size, although the extent of such benefits will depend on the impacts caused by other members of the population.

Challenges associated with harvesting also extend to plants as collection techniques often do not remove entire organisms or leave behind seeds and other reproductive parts that can trigger new populations. In addition, high removal rates are often necessary for invasive plants to achieve a decline in population density. For example, it was estimated that garlic mustard (*Alliaria petiolata* Bieb.) control efforts may only be successful if more than 85% of adults or 95% of rosettes were removed annually (Zipkin et al. 2009).

Complete eradication of the target species may not always be necessary as some species may face extirpation from natural disasters or demographic, environmental, or genetic stochasticity. Understanding the minimum viable population size for an invasive species population will determine target densities for control operations. Great Britain recognized this important aspect in 1981 when the country began an intensive nutria (*Myocastor coypus* Molina, 1782) eradication program. The campaign was designed using a long term study on nutria population ecology that focused on reproductive parameters and considered limiting factors such as the effect of trapping and cold weather. This background analysis produced population simulations that estimated the cost of the program by calculating the numbers of trappers and amount of time needed for eradication. In 1989, complete eradication of nutria was declared and the program was terminated, attesting that eradication of an invasive species is possible with adequate knowledge of the species' population ecology (Gosling and Baker 1989).

Biological overcompensation

If demographic structure and density-dependent processes are not considered, the removal of targeted invasive species may lead to unanticipated consequences. For example, removal of surplus individuals may make survival easier for those that remain (Zipkin et al. 2009). In these circumstances, increased mortality may increase population abundance as a reduction in numbers is offset by higher reproductive and survival rates due to an increase in available resources (Caughley 1977). This concept of biological overcompensation was observed in the 2002 – 2003 Australian Victorian Fox Bounty Trial, in which hunters presented fox tails at a collection point for payment. The trial removed approximately 20% of Victoria's red fox (*Vulpes vulpes* Say, 1823) population; however, this outcome had counterproductive effects. The reduction in numbers increased the amount of available resources for survivors, improving their chances of rearing a healthy litter, thus unintentionally stimulating a population increase (Faithfull and Frankston 2005). While other invasive species control methods could produce this same result, biological overcompensation may obstruct the ability of a harvest program to deliver a long-term reduction of the target population and the damages that incur.

Species dispersal and occupied range

In circumstances where eradication is achieved at a local scale, re-invasion from surrounding areas remains possible, emphasizing the need for sustained prevention and containment measures. Re-invasion is the primary reason why species can be successfully eradicated from islands, yet

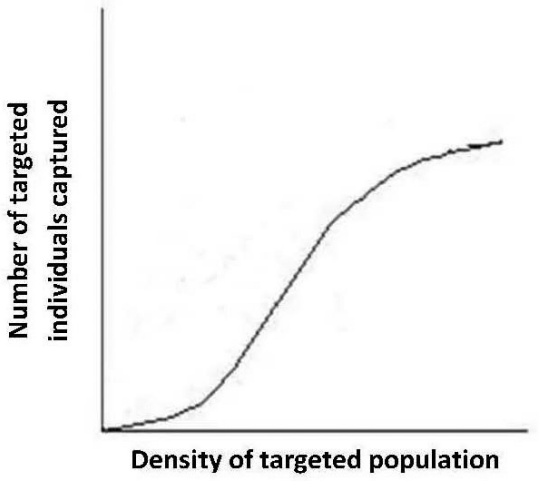

Figure 1. Holling's type III functional curve illustrates that when prey abundance is low predators consume a lower proportion of the prey population (Adapted from Holling 1959).

similar efforts fail on the mainland (Bonford and O'Brien 1995). As noted above, nutria populations in Great Britain were effectively detected and contained and eventually eradicated. Replication of the Great Britain program is unlikely to eradicate nutria from the entire invaded range in the United States, although some success may occur in localized regions. Nutria populations in the United States are much higher and widespread than recorded in Great Britain; populations in Louisiana alone are about 10 times larger than the previously infested area in Great Britain (LWF 2012a). Consequently, eradication may not be a viable option because of the greater financial and staff resources that would be required to achieve results over the larger geographic and population scales.

Shortly after their nutria control operation, Great Britain used similar methods in an attempt to control mink (*Mustela vison* Schreber, 1777) populations. This time the program failed, likely a result of the high dispersal rates and long dispersal distances of the mink (Bomford and O'Brien 1995). This demonstrated that eradication measures that work well for one species in a region may not work for others as species differ in their biological characteristics and ecological niches. For example, species that are highly mobile, disperse long distances, or are already established in a large geographical area may not be good candidates for eradication by incentive programs.

Evaluating program success

Monitoring is essential to determine the effectiveness of any incentive program. However, estimating population size has its own challenges. Ideally, the target species should be detectable at low densities and found relatively easily; if a species is cryptic or lives in an isolated area, an inhospitable environment, or an area that cannot be easily accessed, it will be difficult to locate and remove. For example, Burmese pythons invasive to the Florida Everglades are cryptic and often hard to find. The snakes' ability to blend in and the difficulty of surveying the terrain not only hinders monitoring efforts, but may prevent incentive programs from reducing numbers in a manner that does not compromise human safety from working in challenging environments.

Estimating the population size of the targeted species may be challenging, yet it is necessary to monitor and evaluate the success of harvest activities and ensure that program management goals have been achieved. Removing the last 1 percent of a target population can cost more than eliminating the first 99 percent (Bomford and O'Brien 1995) as more time and resources will be necessary to locate and remove individuals as their density declines (Dedah et al. 2010). Nonetheless, continued efforts are important as invasive species populations can recover quickly even when only a few members of the population remain. Holling's Type III functional response curve hypothesizes that at low densities the chance of a predator (in this case, the harvester) encountering prey (or targeted individuals) is rare (Figure 1); hence at low prey densities the response of the predator is weakened (Holling 1959). Although other factors may influence the success of a predator, including the ease of detection and behavior of the prey, Holling's work illustrates the significance of species density when attempting to locate and capture prey. Comparatively, incentive programs may lose their effectiveness as the target species becomes rare because the benefits, for the same amount of time or financial resources, do not sufficiently motivate the greater effort needed to capture the remaining individuals. If striving for species eradication, natural resource managers should be prepared to incorporate adaptive management or increase incentives when density and species impacts are low or nearing the minimum viable population size. If a program ends before goals are achieved or activities are not sustained to keep target populations at acceptable levels, populations

may rapidly return to pre-program levels. This may result in wasted time and funds and provide opportunity for criticism which may impede future control efforts.

An alternative strategy managers may consider, if eradication is the goal, is to employ conventional control measures at early stages of the program to reduce population levels. Conventional measures may include physical removal, chemical treatment, or biological control, either individually or as part of an integrated pest management strategy. Once no longer effective, these measures may be replaced with incentive programs to retrieve the last remaining individuals. Since the target population is expected to be difficult to locate at this stage, a high financial incentive will likely be needed to encourage participation in the program. This high cost may be worthwhile if the program prevents suppressed populations from rebounding or achieves eradication of the species. Similar strategies have been used to locate species soon after an introduction has occurred. The New Zealand Department of Conservation offered a $300 reward for information that led to the capture of the red-vented bulbul (*Pycnonotus cafer* Linnaeus, 1766) (One News 2013; Ministry for Primary Industries 2013). One of the most invasive bird species in the world, this species presents a major threat to the country's native birds and fruit and vegetable crops. These invasive birds had been successfully eradicated from New Zealand before, verification that reintroduction can occur and rapid response actions can avert the risk of harmful invasions.

Ecological considerations

Management of invasive species through comercialization and harvest may have unintended consequences for native species. Potential damage to non-target species must be considered before implementing any control program. Native species populations may be impacted directly through by-catch or increased human disturbance. Ecological complexities may also cause unexpected consequences for native species. Biological invasion often results in the loss of biodiversity, resulting in altered trophic relationships and ecosystem processes, signifying that restoring native communities is often not as simple as removing the invader (Zavaleta 2001).

Possible impacts from invasive species removal include increasing opportunities for a more problematic species to flourish. For example, in Hawaii the removal of wild pigs (*Sus scrofa* Linnaeus, 1758) and sheep (*Ovis aries* Linnaeus, 1758) have increased cover of flammable invasive grasses in many of the state's lowland grasslands. Increased fire frequency has created a positive feedback loop among invasive grasses, fire, and loss of native woodland and forest species (D'Antonio and Vitousek 1992). Other invaders may render habitat unsuitable for native species, as in the case with invasive saltcedar shrub (*Tamarisk* spp.). Saltcedar removal has become increasingly complex and repeatedly delayed in the western United States because it provides significant nesting habitat for the endangered southwestern willow flycatcher (*Empidonax trailii extimus* Phillips, 1948) (Zavaleta et al. 2001). Re-establishment of native vegetation used by the songbird may not be possible as a result of the lowered water tables and salinized soils attributed to the saltcedar invasion (Taylor and McDaniel 1998), thereby suggesting that the benefits from saltcedar may outweigh its harm.

Given the numerous, complex interactions among species and their environment, it is difficult to predict the outcome of invasive species removal. Careful evaluation of the functional roles of invasive species within ecosystems and possible trophic interactions with native species should be conducted prior to initiating any incentive-based program. In addition, once the target species has been appreciably diminished or extirpated from the management area, native habitat and species restoration and long-term monitoring are crucial to achieve management goals.

Human health considerations

While incentives can offer opportunities to educate and include the public in invasive species management, serious consequences can result if incentive programs do not include guidance on proper techniques for capturing and handling the target species. For example, lionfish tournaments and derbies have risen in popularity and serve as a means to raise awareness and manage growing populations of the invasive fish. However, improper handling of the species' venomous spines can cause significant human harm ranging from pain and swelling to tachycardia, seizures, and temporary paralysis (Morris and Whitfield 2009). Additional risks may be associated with promoting invasive species as a viable food source. Lionfish species (*P.volitans* and *P.miles*) have been added to the Food and Drug Administration's ciguatera watch list, a list of several fish species that harbor the foodborne toxin and represent a possible health

hazard when ingested (Cearnal 2012; FDA 2013). As of July 2014, no known cases of ciguatera fish poisoning from eating lionfish have been confirmed. Further, recent research suggests that proteins in the lionfish venom may mimic ciguatoxin, possibly creating false positives in testing procedures. This evidence does not eliminate the possibility that lionfish may carry the toxin, only that the risk to public health is no greater than that for grouper and similar fish species (Wilcox and Hixon 2014).

In another case, Clark et al. (2008) examined the suitability of Mitten crabs (*Eriocheir sinensis* Edwards, 1854) within the River Thames for human consumption. After testing numerous crabs for the presence of the lung fluke parasite *Paragonimus westermani* (Kerbert, 1878), the bacteria *Vibrio parahaemolyticus* (Fujino et al. 1951), concentrations of trace metals, polycyclic aromatic hydrocarbons, and several other organic pollutants, the investigation concluded that Thames mitten crabs were fit for human consumption. By appropriately conducting a health assessment, as they might do for assessing any fishery or commercial market, managers are in a better position to determine viable control options for the targeted population.

Socioeconomic considerations

Establish clear management goals and objectives

Prior to initiating an incentive program, potential costs and risks must be evaluated to help determine the overall goal of the program. Eradication of invasive species is not necessarily the optimal choice in all situations (Olson and Roy 2002). The decision of whether to pursue eradication may be dependent on the species' habitat or population size such that management goals may differ even between populations of the same species. For example, nutria have significantly invaded both Chesapeake Bay and Louisiana marshes, yet strategies to manage these populations drastically differ. Chesapeake Bay officials decided to pursue eradication because the population size within the Delmarva Peninsula was estimated at approximately 100,000, a size that partners felt was small enough to allow for eradication given available resources. Bounties are illegal in Maryland, therefore authorities have never encouraged public harvest; instead, the program relies on wildlife specialists from the U.S. Department of Agriculture (USDA) to locate and remove individuals. The program began with a "knock-down" phase which employed firearms, traps, and dogs when high density populations could be easily located. As the population density decreased, the program switched to other methods including lures and "Judas" nutria that relied on the animal's social behavior to lead to other captures (USFWS 2012c).

In contrast to the Chesapeake Bay region, hundreds of thousands of nutria exist in Louisiana (Jordan and Mouton 2011), such that the Louisiana Department of Wildlife and Fisheries (LWF) acknowledged that eradication is not a viable option (LWF 2012a). Instead, Louisiana's Coastwide Nutria Control Program consists of an economic incentive payment of $5 for each nutria tail collected by registered participants. The goal of the program is to encourage the annual harvest of up to 400,000 nutria from coastal Louisiana and thereby lessen the destructive impacts that the species inflicts on the state's wetlands (LWF 2012b).

Eradication, regardless of the control measure used, can be a high risk undertaking and should only be pursued if there is a strong commitment and ability to remove every individual below the threshold for reproductive establishment. In a review of eradication success, Bomford and O'Brien (1995) found that nutria eradication in the United Kingdom was successful in part because the value of the agricultural and environmental resources protected by the eradication was greater than the cost of the program (more than $600 per animal to capture, totaling over $3 million). However, the authors reported additional case studies, such as feral goat control programs in Australia, where it was unclear whether eradication was preferable to long-term control. In some cases, it may be more effective to control impacts within a pre-determined acceptable limit. For instance, male sterilization and other control methods for invasive sea lamprey have reduced abundance by 90 percent (GLFC 2012). Integrated sea lamprey control strategies implicitly acknowledge that current technology and efforts cannot reduce populations to zero, but numbers can be maintained to an acceptable level. Likewise, the Pikeminnow Sport Reward Fishery Program in the Pacific Northwest does not seek eradication of the northern pikeminnow (*Ptychocheilus oregonensis* Richardson, 1836), but rather a reduction of larger, older fish to reduce impact to salmon populations (*Oncorhynchus* species) that the northern pikeminnow preys upon. This reduction is realized though a bounty program supported

by Bonneville Power Administration (BPA). Anglers are paid $4-8 for each northern pikeminnow that they capture, with tagged "prize" fish worth $500. Since 1990, over 3.9 million northern pikeminnow have been removed by the program and predation on juvenile salmonids has been cut by an estimated 40% (PSMFC 2012).

In New Zealand, recreational hunting and commercial hunting has been used as tools to keep numbers of some invasive species low enough to meet conservation needs. For example, Parkes et al. (1996) found that harvest of the invasive red deer (*Cervus alaphus* Linnaeus, 1758) kept populations low enough to significantly reduce environmental impact where eradication could not be realized. Nonetheless, consistent with the idea that management goals and control measures will vary based on the species ecology and management area, the authors also concluded that similar strategies would be unlikely to afford any advantage in controlling possums (*Trichosurus vulpecula* Kerr, 1792) compared to other methods.

Any effort that favors long-term control over eradication requires dedicated and sustained funding, yet control costs are often less than the ecosystem and economic damages resulting from invasion. Managers need to consider the financial costs and risks of pursuing eradication versus sustained control operations and weigh those considerations against the long-term costs of the presence of the invasive species.

Market economics

The success of commercial markets and incentive programs to control invasive species will depend in part on the value of the harvested commodity, the cost associated with the harvest, the minimum profit acceptable to the harvester, and the value of the resource being protected. Depending on the anticipated end product, some invasive species may demand a higher market price. A bioeconomic model may be used to analyze the potential role of incentives to achieve program goals. Dedah et al (2010) examined Louisiana's Coastwide Nutria Control Program (CNCP) to develop a model that relates annual nutria harvests to a suite of economic and environmental factors. The model found that increased incentives had a positive influence on numbers harvested, indicative that bounty programs may serve as a successful method to reduce, but not eradicate, nutria populations. Bioeconomic models should be customized for each incentive program and include the specific programs goals, management area, level of participation, and life history characteristics of the targeted species.

The marginal cost and effort needed to capture the species is expected to increase as the population decreases, thus managers need to plan to either raise the value of the incentive used or employ other control mechanisms. For example, a review of Australian feral pig control programs concluded that commercial harvest may reduce densities, but traditional control measures may be more effective once the threshold is reached where the public no longer finds it profitable to harvest the species (Choquenot et al. 1998). Such adaptive management or supplementary control methods may enhance the effectiveness of the program; however they may also reduce the economic viability of incentive programs by removing organisms that could otherwise be harvested. Establishing and communicating clear program goals is necessary to anticipate and mitigate these issues.

Harvest incentive programs may create a source of income that may generate pressure to sustain the targeted species rather than eradicate it; however, the overarching program goals should be a reduction in the targeted population and not a profit for harvesters. To avoid potential disputes, an exit strategy should be prepared to restore or develop native fisheries for utilization. For example, region-wide eradication is unlikely for lionfish populations in the Gulf of Mexico and Caribbean waters, yet incentivized harvest may effectively reduce lionfish numbers and minimize impacts in localized areas (Frazer et al. 2012; Morris 2012). Combining lionfish harvest programs with a change in fishery management practices to sustain high numbers of native groupers (subfamily *Epinephelinae*) may allow the ecosystem to return to a state where harvest of native species once again becomes practical. This is particularly important as lionfish populations diminish and fishing communities seek alternative available fisheries. As an additional benefit, at high enough populations, grouper can serve as a natural control mechanism of lionfish (Mumby et al. 2011).

In some circumstances, the long-term economic benefits of harvest may outweigh the economic or environmental damages resulting from the invasion. If this occurs, the species may no longer be considered invasive, but rather a beneficial non-native. If resource managers determine the economic benefits of a species outweigh the costs of any deleterious effects, management

may need to shift to sustainable development strategies for harvests. Such an approach should be considered a means of last resort, as it means adapting to irreversible ecosystem changes and adopting the species as a permanent presence, an approach that is generally not preferred (Lambertucci and Speziale 2011). For example, Australian *Acacia* species in South Africa are important to the plantation forestry industry, but also have significant ecosystem impacts. Management of this industry has led to consideration of a number of control options that allow cultivation of the plants and maximization of benefits, while attempting to limit their spread and minimizing their damage (van Wilgen et al. 2011).

Unintended outcomes

Perhaps the biggest challenge of promoting harvest of invasive species is its potential to generate perverse incentives that could unintentionally cause the further spread of the target species or have other undesirable effects. People may come to rely on the income that bounty programs or commercial markets generate, discouraging eradication or control efforts (Tisdell 1982 and Ramsay 1994, as cited by Choquenot et al. 1998). The public may develop a "taste" or preference for the species, even without a direct economic incentive, and value its long-term presence equally alongside native species. This may encourage breeding programs or intentional release into management areas or previously non-invaded habitats. Such actions have been a persistent problem in the angling community, where people have illegally stocked favorite game fish into non-native habitats, threatening restoration and native species (Johnson et al. 2009). In the notorious cobra effect, residents of colonial Delhi realized that the bounty offered by the British government for venomous cobra snakes (family *Elapidae*) was higher than the cost to breed the targeted species and subsequently began to raise the snakes for income. Once aware of the breeding activities, the government ended the bounty program. Breeders set the now-worthless snakes free, leading to a significant increase in the snake population (Walker 2013). In a related example, a bounty for rats was established in Hanoi, Vietnam in the early 1900s. This effort resulted in a collection of tails, but left several tail-less rats alive and free to reproduce, thereby increasing revenue for the bounty participants. Moreover, some individuals were found cultivating rats instead of surrendering them to the government to collect the bounty (Vann 2003).

Government intervention

Government agencies may provide seed funds to encourage consumers and private industry to develop a market for a particular species. However at high population densities, financial incentives may not be needed as market prices alone may support active harvest. Size classes may also be important; for example, Tsehaye et al. (2013) suggested that stronger economic incentives might be needed to encourage harvest of smaller Asian carp which have lower commercial values and whose harvest may have higher bycatch and damage gear. Alternatively, if commercial partners provide start-up funds for a target species, resource managers may have a responsibility to avoid employing other control measures until private partners yield a return on their investment. In this circumstance, the key role for managers and government may be to conduct outreach to encourage additional investment and ensure regulatory flexibility that allows harvesting to continue. Once the population density decreases below the threshold where the species is profitable or desirable to catch, bounties and other incentives could be used to subsidize the market. If other control or eradication measures are not employed, these additional incentives may be needed to ensure the invasive population falls below its capacity to reproduce and re-establish. Consideration should be given to potential complications with initial or supplemental incentives from the government. For example, what happens if a successful control technology is developed before private industry receives a return on investment? Open communication during development of control strategies between government and stakeholders should help to address these and related issues.

Administrative and legislative issues

Not every policy fits every species. For example, species listed as injurious under Title 18 of the Lacey Act (18 U.S.C. 42) are restricted from importation or interstate movement. By prohibiting import or exchange, the Lacey Act and similar legislation may deter markets where live species are desirable. This situation was realized in 2012 after the U.S. Fish and Wildlife Service (USFWS) added several large constrictor snake species to the injurious wildlife list (USFWS 2012a). Several of these species are owned privately, while others are invasive in the wild (Dorcas et al 2012). Under the injurious wildlife provisions of the Lacey Act, specimens in private hands at the

time of listing can be moved and sold within a state as long as there is no state law or regulation prohibiting such action. Specimens can also be exported out of the country, but the species cannot cross state lines while being transported to the airport and the plane exporting the species cannot land in another state before it reaches its final destination (FWS 2012b). To create an incentive that would allow private owners to move their snakes outside the United States Representative Fleming (R-LA) introduced, H.R. 2158, the Expedited Departure of Certain Snake Species Act, in the 113th Congress. This legislation would allow the snakes to make intermediate stops without violating the Lacey Act. If passed, it remains unclear whether this legislation will achieve the purpose of providing an incentive for owners (and potentially harvesters) to expedite removal of the snakes or, alternatively, allow breeders to continue to sell listed species on the international market without reducing U.S. populations.

Private property rights are also an important consideration for incentive programs. Legislation may be needed to encourage or allow access to private lands to ensure all targeted individuals in a population have been removed. For example, the Wisconsin Department of Natural Resources (WDNR) has promulgated regulations that allow inspectors to enter private lands, with a warrant if needed, to ensure that prohibited species are not present (WDNR 2013). Legislation may also be needed to ease regulation of incentive programs as several state laws prohibit or restrict the use of incentive programs to manage invasive species populations. Currently, bounties are unlawful or limited in the states of California, Maryland, Massachusetts, New Jersey, New Mexico, New York, and Oregon (Born Free 2014).

Decision makers have to be sensitive to issues including the timing of initial start-up incentives, the authority and influence needed to increase harvest opportunities geographically and seasonally, possible conflicts with endangered species, and bycatch or other environmental damage caused by harvesting activity. It may also be necessary to ease regulatory burdens that hinder the capture and utilization of invasive species. In 2013 the Florida Fish and Wildlife Commission waived the license requirement for catching lionfish with certain gear types and eliminated the catch limit (FWC 2013b). Finally, some government agencies have been reluctant to support the sale of wild game that is not regulated for safety and quality (Tometich 2013). As a result, the sale of harvested invasive species may be limited if government inspections are not available to ensure safety or promote public trust in the quality of the product.

Outreach

Incentives programs typically include the public and other environmental management stakeholders, thereby providing opportunities to raise awareness of invasive species threats and actions that can be taken to prevent future introductions, establishment, and spread. By engaging the public and encouraging harvest, managers may further be able to identify where populations of invasive species are found and develop appropriate control and rapid response efforts. For example, in 2012 Maryland instituted a lottery program that offered a potential prize to anglers who reported a snakehead (family Channidae) catch. The information collected from the reports assist in assessing the abundance, spread, and impact of the invasive fish (Maryland Department of Natural Resources 2012).

Stakeholder engagement may also help resolve differences prior to program implementation. For example, what is considered a pest by one person may be an essential income source to another and a source of recreational pleasure to a third. For example, depending upon the audience, feral pigs may be perceived as pests that destroy property and carry disease or as an asset valuable with recreational hunting value (Lewis 1966; USDA 2013). Outreach and facilitated discussions with the public can help resolve disputes before program implementation begins.

Strong public outreach is essential as harvest programs have a greater likelihood of success if the public understand and accepts the need for control (Hassall and Associates 1998). Outreach should communicate the long-term impacts of the target species on the environment, economy, and public health in order to build program support and encourage active participation. It can also help the public understand the long-term benefits of eradication or control and the need to eventually phase out the market and short-term benefits that the species generates. Educational programs can also generate financial support from decision-makers and ethical support from stakeholders that may not favor the killing of large numbers of animals for moral, emotional, or cultural reasons.

Public opinion and disagreements over the targeted species' welfare may impede harvest efforts, as demonstrated by contract trapping operations of invasive rhesus monkeys (*Macaca mulatta* Zimmermann, 1780) in Florida's Silver River State Park. Many of the captured monkeys were sold to research facilities, which raised objections from animal rights groups. Eventually the strong opposition forced state officials to halt all control efforts in 2013. Although the monkeys pose a health threat to humans, alternative measures have not yet been identified to deal with the growing monkey populations (Tampa Bay Times 2013).

Disapproval of bounty programs for ethical or moral reasons may also stem from the encouragement of inhumane methods that require presentation of the skins, heads, or other body parts of the target species for payment. Incentive programs should emphasize euthanasia techniques that render the death of the target species as painlessly as possible (MRBP 2007). Although the capture and killing of the target species is expected to occur in outdoor environments, this does not diminish the ethical obligation to reduce the animal's discomfort. Humane protocols should be developed for the target species, taking into account the unique anatomical characteristics of the species and the likelihood that harvest will occur by a nonprofessional in a remote setting (AVMA 2007). Promotion of natural resource management goals and protection of native species from harm may avoid many of the ethical and moral concerns associated incentivized harvest (Bulte and Rondeau 2005). However, proper training of program participants and the use of humane guidelines may alleviate lingering opposition.

Combining strategies

There is no "one size fits all" approach for the control and management of invasive species. In some circumstances multiple control strategies, including incentivizing harvest, may be necessary to effectively manage a species. In New Zealand, recreational hunting and commercial hunting are two of many techniques used to manage environmental resources. In the case of Asian carp, commercial fishing was only one of multiple approaches identified to control populations within the Mississippi River Basin (Parkes and Murphy 2003; ARCCC 2012). Overfishing is being used to provide some level of control while research efforts continue on population control and eradication techniques (MICRA 2013).

Biological characteristics and ecological preferences differ from species to species. Therefore, control methods that work well for one species or region may not be technologically feasible or effective for another. Timing of which tool to use is important, and not all tools will be needed for all species. Natural resource managers may consider combining strategies for integrated pest management, thereby using harvest at one phase and alternative control measures at another or on different scales. A clear plan showing how and when strategies will be utilized will help minimize long-term investments.

Conclusions and recommendations

Despite the widespread attention harvest has received, there are limited case studies where its value has been successfully demonstrated for control or eradication, with relatively few analyses (e.g., Parkes et al. 1996; Parkes and Murphy 2003; Nuñez et al. 2012) or recommendations available (e.g., MRPB 2007). Programs that encourage incentivized harvest may be an effective management tool in targeting small, distinct populations or they may play a supplementary role within larger control or eradication programs. As with other control and management options, success depends upon multiple variables, many of which require evaluation on a case by case basis. Table 1 provides generalizations for applying incentivized harvest, although the efficacy of commercial markets and incentive programs to control invasive species varies by region and species. The use of such programs, however, requires careful review, planning, and monitoring to achieve success and ensure that they do not unintentionally lead to the further spread of invasive species or cause additional harm to native species.

Cooperation between management agencies and stakeholders will result in stronger, more efficient, incentive programs. Commercial markets for invasive species may develop without involvement from government agencies; however, these markets may benefit from the expertise and resources within these agencies (and vice versa). In many cases there will be a need for partnerships between government, natural resource managers, and private industry to develop and implement efficient programs for the control invasive species and to mitigate the threats to native ecosystems.

Incentivized harvest is just one of numerous strategies that exist to manage and control invasive species. Dedicated funding for invasive species management is often limited; for that reason,

Table 1. General characteristics to establish feasibility for an effective harvest incentive program for invasive species.

Favorable Characteristics	Unfavorable Characteristics
Target species found in low densities or localized areas	Target species disperses long distances or is established in a widespread geographical area
Target species is easily identified	Target species is cryptic
Target species is found without significant physical effort	Target species lives in an isolated or inhospitable environment
Low risk to human health or safely regarding the handling, use, or consumption of the target species	Species poses significant human health risks
Clear management goals and objectives	Assumption that incentive programs are "free" and self-sufficient
Strong public support for control of the target species	Public members oppose control for ethical, moral, or cultural reasons
Ability to monitor and evaluate success of harvest activities	Changes in population density cannot be estimated
Support to continue program until management goals are achieved	Support for program diminishes as target density and impacts decrease
Exit strategy included in management plan	Unintended outcomes including fraud and intentional introduction
Native species can be provided following eradication of the target invasive species	Replacement opportunities for the target invasive species do not exist
Supplementary prevention and containment measures are in place	Individuals are able to immigrate back into the management area
Demand for target species is high or could be developed	Demand for target species is low or limited
Anticipated benefits from harvest are greater than the cost to achieve conservation goals	Harvest costs are more expensive than other control operations

resource managers should consider conducting an analysis of viable options to identify the most cost-effective solution for their needs.

It is critical to evaluate potential challenges and set realistic goals and expectations for market-based incentive programs. Understanding biological, ecological, human health, and socioeconomic considerations is also essential; promoting harvest without considering these underlying criteria will likely result in ill-used time and resources. The recommendations below are offered to assist in development and implementation of an incentive program. Figure 2 illustrates the relationships between these recommendations as well as many of the concepts discussed throughout this paper. This diagram in not intended to depict all potential actions and necessary information, but rather demonstrate the numerous considerations and knowledge that is required to build a successful harvest incentive program.

Recommendations for incentivized harvest programs

1.Define the management plan and objectives

Managers need to determine if complete eradication of the species is feasible or, if not, what level of control is necessary to meet practical management objectives. Harvesting invasive species has the potential to serve as an effective tool, but is not a panacea and may not achieve conservation goals or necessarily provide more benefits than other approaches. All management plans utilizing incentivized harvest as a method of control should include an exit strategy to avoid any complications with ending a program that generates revenue for the private sector.

2.Understand the costs

Sanctioning the harvest of invasive species for commercial or recreational purposes is not necessarily "free." Administrative and other costs are needed to operate any control program. The optimal level of control should be based on a marginal cost analysis that compares the anticipated benefits of control or eradication to the costs of control.

3.Understand the target species' population dynamics

Managers need to anticipate the program's impact on the target population and determine the number of individuals that must be removed for the program to be effective. This requires an understanding of the life history characteristics of the target species, including density dependent processes, demographic structure, specific vital rates, and minimum viable population size.

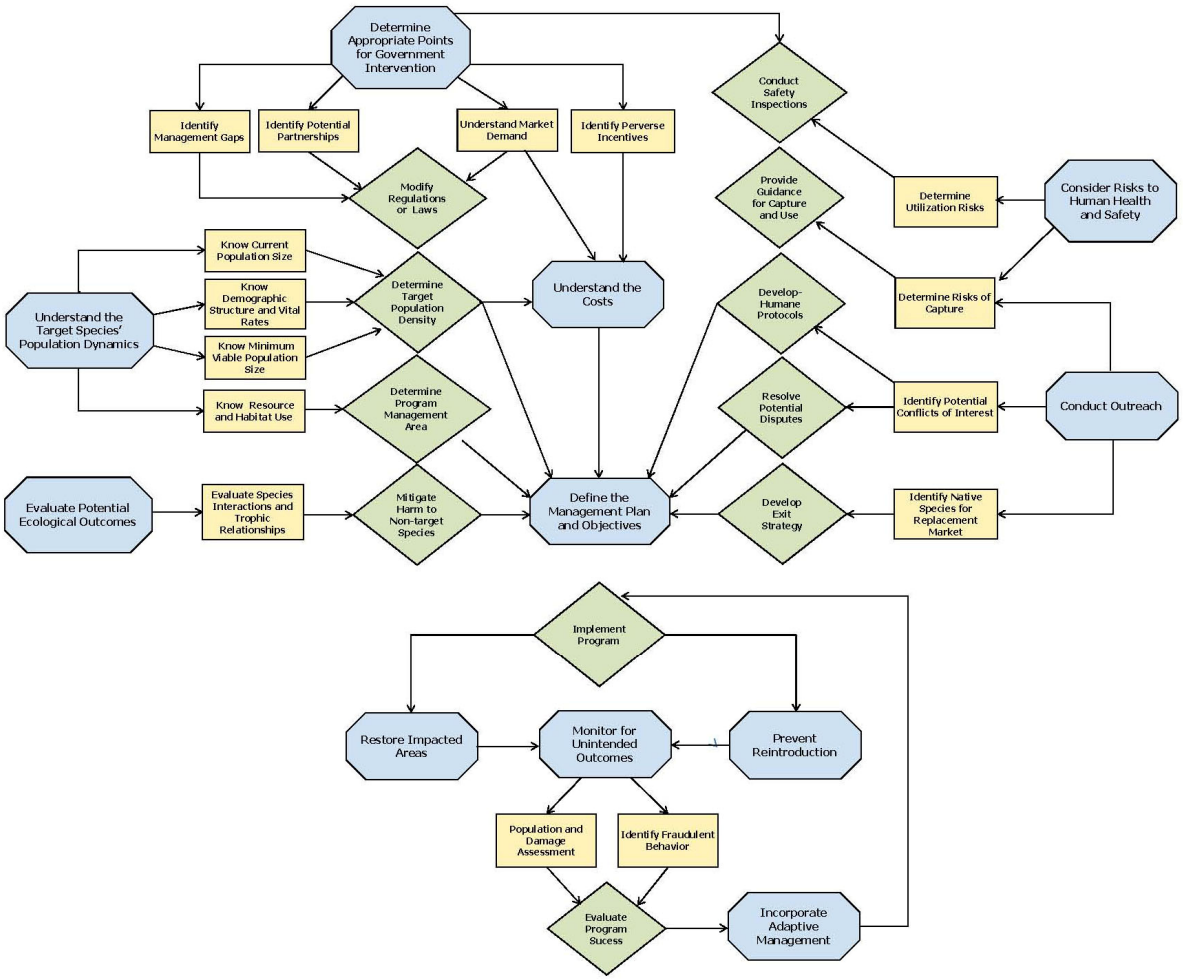

Figure 2. Diagram depicting some of the relationships between the recommendations and concepts discussed throughout this paper. The blue octagons illustrate the 11 recommendations that conclude the paper. Yellow rectangles represent critical information to fulfill the recommendations whereas the green diamonds are the resulting actions items.

4.Consider risks to human health and safety

Before encouraging harvest, resource managers need to ensure risks from the target species to human health through handling or its intended use are minimized. Participants in incentive harvest programs should be properly trained in locating and capturing techniques.

5.Evaluate potential ecological outcomes

Invasive species alter biodiversity and ecosystem processes, possibly resulting in unexpected consequences. Species interactions and effects of removing an invasive species from the ecosystem via harvest should be evaluated prior to program start.

6.Monitor for unintended outcomes

Incentive programs and commercialized harvest of invasive species may create situations that can negate long-term control or eradication efforts. Prior to program implementation, consideration should be given to human behavior and potential responses, including committing fraud by breeding on private property, intentionally introducing the species into new areas, or other means that result in additional spread of the target species in order to reap the benefits. The program should be adequately supervised to prevent such occurrences.

7.Prevent re-introduction

Harvest based efforts will be unsuccessful if individuals can immigrate back or are released into the management area. Prevention, monitoring, and rapid response programs remain necessary components.

8.Incorporate adaptive management

Monitoring is essential to determine the effectiveness of the program. Incentivized harvest may work early on when there are large, easily accessible populations, but other control measures may be needed as population densities decline or if unintended consequences occur. Alternatively, certain incentives may be useful to retrieve the last, hard-to-find individuals. Control efforts should include periodic population and damage assessments to determine when and if incentives should be implemented.

9.Conduct outreach

Public support for control and eradication programs, including those that involve incentives, is essential. Success is more likely if the public understands and dislikes the long-term harm the target species can cause to native species and habitats. Outreach materials should be clear about program goals and encourage public engagement, yet should discourage the long-term availability of the target species.

10.Restore impacted areas

Solely removing the invasive species from an area is not enough to return the ecosystem to its pre-invaded state. Restoration of native species and habitats can help address local impacts to the environment and ensure that long-term benefits of native restoration outweigh the short-term benefits accrued by harvest.

11.Determine appropriate points for government intervention

Financial support from state and federal government agencies to encourage harvest may be more necessary when population levels of the invasive species are low. At high population levels, intervention may be reduced to providing outreach and advocating harvest by keeping regulatory options flexible. Agencies and legislatures also need to review and consider new authorities or regulations that may be needed to more effectively manage and control the target invasive species.

In addition to the above recommendations, natural resource managers and other decision-makers are also advised to review and consider the recommendations developed by the MRBP described earlier (MRBP 2007). The recommendations, while largely different, complement the ones presented in this paper.

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References

Asian Carp Solution (2012) Can't Beat 'Em, Eat 'Em. http://www.asiancarpsolution.com/asiancarpsolution_plan.pdf (Accessed 12 December 2012)

[ACRCC]. Asian Carp Regional Coordinating Committee (2012) Asian Carp Control Strategy Framework. http://asiancarp.us/documents/2012Framework.pdf (Accessed 12 December 2012)

[AVMA]. American Veterinary Medical Association (2007) AVMA Guidelines on Euthanasia. https://www.avma.org/KB/Policies/Documents/euthanasia.pdf (Accessed 12 December 2012)

Bartel RA, Brunson MW (2003) Effects of Utah's coyote bounty program on harvester behavior. *Wildlife Society Bulletin* 31: 738–743

Barbour AB, Allen MS, Frazer TK, Sherman KD (2011) Evaluating the potential efficacy of invasive lionfish (*Pterois volitans*) removals. *PLoS One* 6: 1–7, http://dx.doi.org/10.1371/annotation/01ecd7b0-1be0-4e2f-87c7-079d5f1a1c32

Bomford M, O'Brien P (1995) Eradication or control for vertebrate pests? *Wildlife Society Bulletin* 23: 249–255

Born Free USA (2012) State Wildlife Bounty Laws by State. http://www.bornfreeusa.org/b4a2_bounty.php (Accessed 28 May 2014)

Bulte EH, Rondeau D (2005) Why compensating wildlife damages may be bad for conservation. *The Journal of Wildlife Management* 69: 14–19, http://dx.doi.org/10.2193/0022-541X(2005)069<0014:WCWDMB>2.0.CO;2

Caughley GC (1977) Analysis of vertebrate populations. John Wiley and Sons, London, England, 234 pp

Cearnal L (2012) Red lionfish and cigatoxin. *Annals of Emergency Medicine* 60(1): 21A–22A, http://dx.doi.org/10.1016/j.annemergmed.2012.05.022

Clark PF, Campbell P, Smith B, Rainbow PS, Pearce D, Miguez RP (2008) The commercial exploitation of Thames mitten crabs: a feasibility study. Department for Environment, Food and Rural Affairs (DEFRA). DEFRA Reference FGE 274, 81 pp

Choquenot D, Caughley J, McLeod S (1998) Scientific, economic, and social issues of commercial use of wild animals in Australia. Bureau of Resource Sciences, Canberra, Australia, 87 pp

D'Antonio CM, Vitousek PM (1992) Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecology, Evolution, and Systematics* 23: 67–87

Dedah C, Kazmierczak RF, Jr, Keithly WR, Jr. (2010) The role of bounties and human behavior on Louisiana nutria harvests. *Journal of Agricultural and Applied Economics* 42: 133–142

Dorcas ME, Willson JD, Reed RN, Snow RW, Rochford MR, Miller MA, Meshak Jr. WE, Andreadis PT, Mazzotti FJ, Romagosa CM, Hart KM (2012) Severe Mammal Declines Coincide With Proliferation of Invasive Burmese Pythons in Everglades National Park. *Proceedings of the National Academy of Sciences* 109(7): 2418–2422, http://dx.doi.org/10.1073/pnas.1115226109

Faithfull I, Frankston DPI (2005) Why the fox bounty did not work. *Under Control* 30: 12–13

[FWC]. Florida Fish and Wildlife Conservation Commission (2013a) 2013 Python Challenge™ competitors turn in 68 Burmese pythons. http://myfwc.com/news/news-releases/2013/february/18/python-challenge/ (Accessed 27 October 2013)

[FWC]. Florida Fish and Wildlife Conservation Commission (2013b) FWC to Permanently Waive License Requirement for Lionfish Harvest. http://myfwc.com/news/news-releases/2013/april/17/lionfish-rule/ (Accessed 30 August 2013)

[FDA]. Food and Drug Administration (2013) Guidance for Industry: Purchasing Reef Fish Species Associated with the Hazard of Ciguatera Fish Poisoning. http://www.fda.gov/ucm/groups/fdagov-public/@fdagov-foods-gen/documents/document/ucm345045.pdf (Accessed 28 April 2014)

Frazer TK, Jacoby CA, Edwards MA, Barry SC, Manfrino CM (2012) Coping with the Lionfish Invasion: Can Targeted Removals Yield Beneficial Effects? *Reviews in Fisheries Science* 20(4): 185–191

Garvey J, Sass G, Trushenski J, Glover D, Charlebois PM, Levengood J, Roth B, Whitledge G, Small BC, Tripp SJ, Secchi S (2012) Fishing Down the Bighead and Silver Carps: Reducing the Risk of Invasion to the Great Lakes. http://asiancarp.us/news/carbondalereport.htm (Accessed 19 April 2013)

[GLFC]. Great Lakes Fishery Commission (2012) Sea Lamprey: A Great Lakes Invader. http://www.glfc.org/sealamp (Accessed 17 December 2012)

Gosling LM, Baker SJ (1989) The eradication of muskrats and coypus from Britain. *Biological Journal of the Linnean Society* 38(1): 39–51, http://dx.doi.org/10.1111/j.1095-8312.1989.tb01561.x

Hassall and Associates Pty Ltd (1998) Economic evaluation of the role of bounties in pest management. Unpublished report for the Bureau of Rural Sciences, Canberra. http://www.feral.org.au/wp-content/uploads/2010/03/00023.pdf (Accessed 8 August 2012)

Holling CS (1959) Some characteristics of simple types of predation and parasitism. *Canadian Entomologist* 91: 385–398, http://dx.doi.org/10.4039/Ent91385-7

[IDNR]. Illinois Department of Natural Resources (2012) Target Hunger Now! http://www.dnr.illinois.gov/Pages/TargetHungerNow.aspx (Accessed 12 December 2012)

Lacey Act. 18 U.S.C. 42: Importation or Shipment of Injurious Mammals, Birds, Fish (Including Mollusks and Crustacea), Amphibia and Reptiles; Permits, Specimens for Museums; Regulations

[ISAC]. Invasive Species Advisory Committee (2014) Harvest Incentives: A Tool for Managing Aquatic Invasive Species. http://www.invasivespecies.gov/global/ISAC/ISAC_whitepapers.html (Accessed 02 July 2014)

Johnson BM, Arlinghaus R, Martinez PJ (2009) Are We Doing All We Can to Stem the Tide of Illegal Fish Stocking? *Fisheries* 34(8): 389–394 http://dx.doi.org/10.1577/1548-8446-34.8.389

Jordan J, Mouton E (2011) Coastwide Nutria Control Program 2010-2011. http://nutria.com/uploads/1011CNCPfinalreport.pdf (Accessed 19 April 2014)

Lambertucci S, Speziale KL (2011) Protecting Invaders for Profit. *Science* 332: 35, http://dx.doi.org/10.1126/science.332.6025.35-a

Lewis JC (1966) Observations of Pen-Reared European Hogs Released for Stocking. *The Journal of Wildlife Management* 30(4): 832–835, http://dx.doi.org/10.2307/3798291

[LWF]. Louisiana Department of Wildlife and Fisheries (2012a) Nutria in Louisiana. http://www.nutria.com/uploads/0232.brochurerev.pdf (Accessed 23 April 2014)

[LWF]. Louisiana Department of Wildlife and Fisheries (2012b) Louisiana Coastwide Nutria Control Program. http://nutria.com/site10.php (Accessed 19 April 2012)

Lozano GR, Anderson L, Akins JL, Buddo DSA, García-Moliner G., Gourdin F, Laurent M, Lilyestrom C, Morris, Jr. JA, Ramnanan N, Torres R (2013) Regional Strategy for the Control of Invasive Lionfish in the Wider Caribbean. International Coral Reef Initiative, 31 pp

Maryland Department of Natural Resources (2012) Help Control the Spread of Snakehead Fish. http://www.dnr.state.md.us/dnrnews/pressrelease2012/032812.asp (Accessed 20 April 2012)

Matsumoto N (2013) Have you ever tried to eat a feral pig? http://www.theatlantic.com/national/archive/2013/07/have-you-ever-tried-to-eat-a-feralpig/%20277666/ (Accessed 13 July 2013)

Ministry for Primary Industries (2013) New Zealand. Red vented bulbul. http://www.biosecurity.govt.nz/pests/red-vented-bulbul (Accessed 25 October 2013)

[MICRA]. Mississippi Interstate Cooperative Resource Association (2013) Asian Carp Commercial Harvest Position Statement. http://www.micrarivers.org/phocadownload/Position_Statements/micra%20asian%20carp%20commercial%20harvest%20position%20statement.pdf (Accessed 27 October 2013)

[MRBP]. Mississippi River Basin Panel on Aquatic Nuisance Species (2007) Guidelines for Developing Commercial Harvest Policy for Aquatic Invasive Species. http://www.micrarivers.org/phocadownload/AIS_Committee/ans%20harvest%20policy%20final.pdf (Accessed 20 April 2012)

Morris JA, Jr. (ed) (2012) Invasive Lionfish: A Guide to Control and Management. Gulf and Caribbean Fisheries Institute Special Publication Series Number 1, Marathon, Florida, USA, 113 pp

Morris JA, Whitfield PE (2009) Biology, ecology, control and management of the invasive Indo-Pacific lionfish: An Updated Integrated Assessment. National Oceanic and Atmospheric Administration (NOAA). NOAA Technical Memorandum NOS NCCOS 99, 57pp

Mumby PJ, Harborne AR, Brumbaugh DR (2011) Grouper as a natural biocontrol of invasive lionfish. *PloS One* 6(6): e21510, http://dx.doi.org/10.1371/journal.pone.0021510

[NOAA]. National Oceanic and Atmospheric Administration (2010) NOAA: More Fishing, Higher Consumption Might Help Reverse Lionfish Invasion. http://www.noaanews.noaa.gov/stories2010/20100806_lionfish.html (Accessed 12 December 2012)

Nuñez MA, Kuebbing S, Dimarco RD, Simberloff D (2012) Invasive species: to eat or not to eat, that is the question. *Conservation Letters* 5(5): 334–341, http://dx.doi.org/10.1111/j.1755-263X.2012.00250.x

Olson LJ, Roy S (2002) The Economics of Controlling a Stochastic Biological Invasion. *American Journal of Agricultural Economics* 84(5): 1311–1316, http://dx.doi.org/10.1111/1467-8276.00395

One News (2013) Bounty offered on invasive bird pest. http://tvnz.co.nz/national-news/bounty-offered-invasive-bird-pest-5633183 (Accessed 12 October 2013)

[PSMFC]. Pacific States Marine Fisheries Commission (2013) Pikeminnow Sport-Reward Program. http://www.pikeminnow.org/info.html (Accessed 25 October 2013)

Parkes J, Nugent G, Warburton B (1996) Commercial exploitation as a pest control tool for introduced mammals in New Zealand. *Wildlife Biology* 2: 171–177

Parkes J, Murphy E (2003) Management of introduced mammals into New Zealand. *New Zealand Journal of Zoology* 30: 335–359, http://dx.doi.org/10.1080/03014223.2003.9518346

Pimentel D, Zuniga R, Morrison D (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* 52: 273–288, http://dx.doi.org/10.1016/j.ecolecon.2004.10.002

Ramsay BJ (1994) Commercial use of wild animals in Australia. Bureau of Resource Sciences (BRS), Department of Primary Industries and Energy, 185 pp

Renaud CB (1997) Conservation status of Northern Hemisphere lampreys (*Petromyzontidae*). *Journal of Applied Ichthyology* 13: 143–148, http://dx.doi.org/10.1111/j.1439-0426.1997.tb00114.x

Sage RF, Coiner HA, Way DA, Runion GB, Prior SA, Torbert HA, Sicher R, Ziska L (2009) Kudzu (*Pueraria montana* (Lour.) Merr. Variety *lobata*): A new source of carbohydrate for bioethanol production. *Biomass and Bioenergy* 33: 57–61, http://dx.doi.org/10.1016/j.biombioe.2008.04.011

Tampa Bay Times (2013) State park will no longer allow trapper to catch wild monkeys for labs. http://www.tampabay.com/news/environment/wildlife/state-park-will-no-longer-allow-trapper-to-catch-wild-monkeys-for-labs/2149199 (Accessed 29 October 2013)

Taylor JP, McDaniel KC (1998) Restoration of saltcedar infested flood plains on the Bosque del Apache National Wildlife Refuge. *Weed Technology* 12: 345–352

Tisdell CA (1982) Wild pigs: environmental pest or economic resource. Pergamon Press Ltd, 456 pp

Tometich A (2013) Invasive Species for Dinner? Add a grain of salt. http://www.usatoday.com/story/news/nation/2013/10/13/invasive-species-for-dinner-add-a-grain-of-salt/2973869/ (Accessed 13 October 2013)

Tsehaye I, Catalano M, Sass G, Glover D, Roth B (2013) Prospects for Fishery-Induced Collapse of Invasive Carp in the Illinois River. *Fisheries* 38(10): 445–454, http://dx.doi.org/10.1080/03632415.2013.836501

[USDA]. U.S. Department of Agriculture (2013) Feral Swine: Ripping and Rooting Their Way across America. http://blogs.usda.gov/2013/04/30/feral-swine-ripping-and-rooting-their-way-across-america/ (Accessed 6 May 2013)

[USFWS]. U.S. Fish and Wildlife Service (2012a) Injurious Wildlife Species; Listing Three Python Species and One Anaconda Species as Injurious Reptiles. 77 Federal Register 3330

[USFWS]. U.S. Fish and Wildlife Service (2012b) February 13, 2012. What the Listing of the Four Constrictor Snakes as Injurious Means For People Who Own Snakes. http://www.fws.gov/fisheries/ANS/pdf_files/Implications%20of%20the%20Injurious%20listing%20for%20the%204%20constrictor%20snakes_US%20Fish%20and%20Wildlife%20Service_Feb%202012.pdf (Accessed 30 August 2013)

[USFWS]. U.S. Fish and Wildlife Service (2012c) Chesapeake Bay Nutria Eradication Project. http://www.fws.gov/chesapeakenutriaproject (Accessed 14 December 2012)

Vann MG (2003) Of Rats, Rice, and Race: The Great Hanoi Massacre, An Episode in French Colonial History. *Colonial History* 4: 191–204, http://dx.doi.org/10.1353/fch.2003.0027

van Wilgen BW, Dyer C, Hoffmann JH, Ivey P, Le Maitre DC, Moore JL, Richardson DM, Rouget M, Wannenburgh A, Wilson JRU (2011) National-scale Strategic Approaches for Managing Introduced Plants: Insights from Australian acacias in South Africa. *Diversity and Distributions* 17: 1060–1075, http://dx.doi.org/10.1111/j.1472-4642.2011.00785.x

Walker P (2013) Self-Defeating Regulation. *International Zeitschrift* 9: 31–37

Wilcox CL, Hixon MA (2014) False positive tests for ciguatera may derail efforts to control invasive lionfish. *Environmental Biology of Fishes*, http://dx.doi.org/10.1007/s10641-014-0313-0

[WDNR]. Wisconsin Department of Natural Resources (2013) Chapter NR 40: Invasive Species Identification, Classification, and Control. http://docs.legis.wisconsin.gov/code/admin_code/nr/001/40.pdf (Accessed 30 August 2013)

Zavaleta ES, Hobbs RJ, Mooney HA (2001) Viewing invasive species removal in a whole-ecosystem context. *Trends in Ecology & Evolution* 16: 454–459, http://dx.doi.org/10.1016/S0169-5347(01)02194-2

Zipkin EF, Kraft CE, Cooch EG, Sullivan PJ (2009) When can efforts to control nuisance and invasive species back- fire? *Ecological Applications* 19: 1585–1595, http://dx.doi.org/10.1890/08-1467.1