Native invaders – challenges for science, management, policy, and society

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The term "invader" is typically paired with adjectives such as "non-native" and "alien", yet native species can also cause ecological and economic impacts that rival those of well-known invasive species. By spreading within their historical range, attaining extreme abundances, and exerting severe per-capita effects as a result of predation or competition, native invaders can create an unusual set of challenges for science, management, policy, and society. Identifying when, where, and why species become invaders in their native ranges requires additional scientific inquiry, outside the current focus of invasion biology. Management strategies often mitigate the symptoms rather than address the causes of problematic native species invasions. Convincing stakeholders to comply with management actions aimed at controlling native invaders creates societal challenges and policy makers must prioritize goals from varied and often conflicting human interests. We illustrate these challenges by highlighting native species that adversely affect threatened and endangered Pacific salmon (*Oncorhynchus* spp).

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Biological invasions, which join synergistically with habitat loss and fragmentation, climate change, natural resource overexploitation, pollution, and a multitude of other anthropogenic factors, are recognized as a leading threat to freshwater, marine, and terrestrial systems. The common notion of an invasive species is one that has become established in a new area and has a measured impact on the ecology and economy of the recipient ecosystem (Valéry *et al.* 2009). The terminology used to describe invasive species (also commonly called foreign, alien, or exotic species; see Valéry *et al.* 2008) has led to the perception that these organisms only originate from far-away regions and are transplanted vast distances, predominantly via human vectors. Consequently, most scientific research, management, and policy efforts associated with mitigation focus on invasive species that have been transplanted from the distant regions where they originated (Wilson *et al.* 2009).

In a nutshell:

- Human alteration of ecosystems may drive native species to invader status, causing ecological and economic damage rivaling that of non-native invasive species
- "Native invaders" complicate the development and implementation of countermeasures in science, management, society, and policy as a result of conflicting goals from diverse human interests
- By identifying the process by which native species become invasive, resource managers may garner support from policy makers and the public for mitigation and control activities to alleviate ecological impacts
- Recovery strategies need to explicitly address the invasive effects of a native species because the nuances of spatial and temporal impacts differ from those of non-native species

Also common but less recognized are species that have become "invasive" in their own native range – these are aptly named "native invaders" (Simberloff 2011). Human activities may create native invaders in three ways. First, human-mediated environmental change facilitates population growth of native species via elevated survivorship and reproduction. The abundance or biomass of a native species can increase to extreme levels, beyond those previously observed, resulting in complete dominance of the community (Goodrich and Buskirk 1995; Valéry *et al.* 2008). Second, habitat modification or other changes in the environment may increase the per-capita effect of native species on the resident community, leading to predation and competition that exceed natural levels (Didham *et al.* 2007). In both cases, native species dominate the community by exploiting niche opportunities created by human activities and/or vacancies resulting from the loss or decline of other native species (Simberloff 2011). Third, human activities, such as intentional stocking, establish new populations of native species within the indigenous distribution where they evolved (Hirner and Cox 2007), thus filling their range without increasing the overall extent of that range. Such invasions often go undetected but they can have considerable effects on recipient ecosystems. Both dominant and range-filling native invaders reflect notable shifts from the past as a result of human activities, and in neither case does the introduction event involve the breaching of a major biogeographic boundary.

Native species can cause similar harmful ecological and economic impacts to those commonly associated with non-native invasive species (ie the subset of non-native

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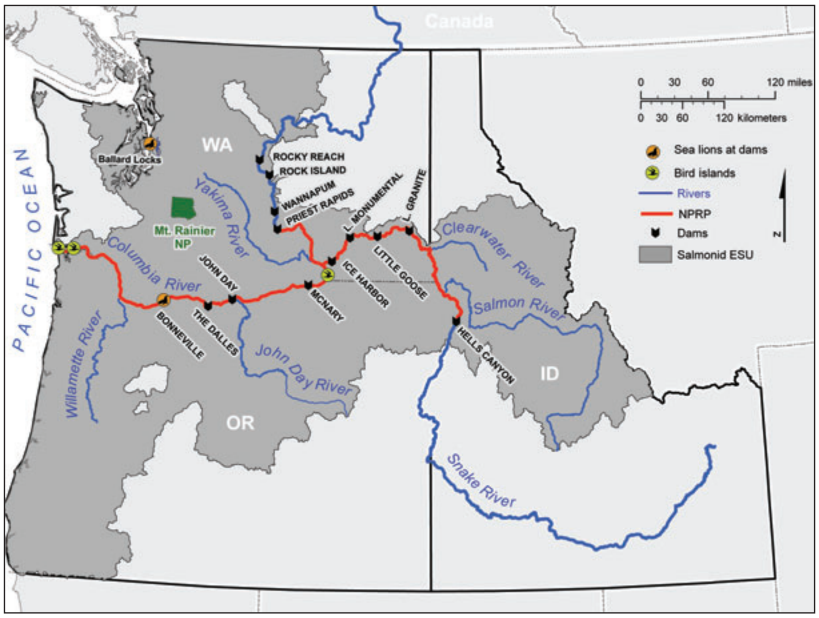

Figure 1. *The distribution of threatened and endangered Pacific salmon, with locations of key human modifications to the landscape and predatory impacts indicated throughout Idaho (ID), Oregon (OR), and Washington (WA), including the Northern Pikeminnow Sport-Reward Program (NPRP).*

species that are considered harmful to recipient ecosystems). Invasions by native species pose a major risk to native fauna and flora because even small shifts in relative abundance among species in the community can lead to substantial changes in food webs (Acevedo and Cassinello 2009; Valéry *et al.* 2009). Native invaders include commonly recognized animals (eg raccoons, *Procyon lotor*) and numerous plants (eg juniper, *Juniperus* spp) (Table 1). In all types of ecosystems, human-mediated processes – such as wildfire suppression, urbanization, predator removal, stocking for recreational opportunities, and climate change – can promote the emergence of native invaders. For example, juniper dominates grasslands in its native range, the western and southwestern US, as a result of human-mediated wildfire suppression (Ansley and Rasmussen 2005), whereas human removal of top predators has led to an overabundance of white-tailed deer (*Odocoileus virginianus*) in the eastern US, resulting in alteration in forest composition by browsing (Horsley *et al.* 2003). Native invaders impact communities and ecosystems through competition, alteration of nutrient cycles, grazing, hybridization, and introgression (Table 1). Regardless of the mechanism, native invaders can reduce or extirpate populations of other native species, thereby altering community structure and, in severe cases, have contributed to a species being listed as threatened or endangered under the US Endangered Species Act (ESA) (Table 1).

Native invaders pose an unusual set of questions for scientific research, management strategies, public education, and policy goals. Yet, to date, there has been no systematic examination of the importance of native invader impacts. The Pacific Northwest (PNW) of the US is emblematic of the difficult and interwoven problems of native species turned invasive (Figure 1). The Columbia River Basin, in particular, is home to four native taxa that have transitioned into invaders during recent decades (Panel 1). These species are in the spotlight because each poses a substantial predatory threat to imperiled Pacific salmon (*Oncorhynchus* spp) listed under the ESA. Here, we examine native invaders in the PNW to illustrate the scientific, management, societal, and policy challenges that arise when native species become invaders.

■ Scientific challenges

Scientists continue to be hard pressed to accurately predict why, when, where, and how a native species will transition into an invader within its own range. Data are often lacking that would allow us to compare current distributions and abundances with historical patterns and therefore to understand whether the present state of a species falls outside the range of typical or historical values. For instance, in the case of Caspian terns (*Hydroprogne caspia*; Panel 1), scientists possess the historical data to demonstrate the chronology by which this species transformed into a native invader. Historically, Caspian terns lived in small colonies scattered throughout inland portions of the PNW (Suryan *et al.* 2004) but more recently, substantial numbers relocated to artificial habitat – created by dam construction and waterway dredging – in the Columbia River Basin (Figure 1). Artificial islands provide excellent nesting habitat, thanks to the stable water levels that result from flood control measures and the absence of native predators (Roby *et al.* 2002; Suryan *et al.* 2004). Similarly, reservoirs above the dams and artificial channels along the Columbia River provide habitat and food supplies for the terns (Maranto *et al.* 2010). This newly created habitat – in combination with abundant food supplies, including juvenile salmon from hatcheries – has allowed the population of Caspian terns to double since 1980 (Suryan *et al.* 2004). Currently, two-thirds of the Pacific coast Caspian tern population reside in the Columbia River Basin (Antolos *et al.* 2005; Maranto *et al.* 2010). Increased food supplies from anthropogenic sources and the absence of predators are common drivers of native invaders. Examples from other regions include Canada geese (*Branta canadensis*) in North America, kangaroos in southeastern Australia, and crows on the Olympic Peninsula of Washington State (Table 1).

Although most natives transition into invaders as an unintentional result of human activities, others stem from deliberate management decisions, such as fish stocking for recreation or food (Cucherousset and Olden 2011).

Table 1. Examples of native species that have invasive effects in their native range occur in all types of ecosystems

Common name	*Scientific name*	*Ecosystem type*	*Human-mediated process creating native invader*	*Invasive effect*	*Mechanism of invasive effect*
Animals					
Barred owl	*Strix varia*	Forests	Forest practices	Diminish native species to Threatened status	Displacing, hybridization
Brown-headed cowbird	*Molothrus ater*	Forests	Forest practices, agriculture, and housing development	Reduce migrant birds	Brood parasitism
Coyote	*Canis latrans*	Shrub and grasslands	Fire suppression and human food sources	Diminish native species to Endangered status	Competition
Crow and raven	Corvids	Coniferous forest	Human food waste	Reduce nest survival of birds	Predation
Elk	*Cervus elaphus*	Alpine grasslands	Predator removal	Alter community structure	Grazing
Geese	*Branta canadensis maxima, Chen caerulescens atlantica, C c caerulescens*	Freshwater, lentic systems	Predator removal	Eutrophication	Grazing
Western gray kangaroo	*Macropus fuliginosus*	Semi-arid woodlands and herb fields	Predator removal	Alter community structure	Grazing
Mountain pine beetle	*Dendroctonus ponderosae*	High-elevation pine forests	Climate change	Tree loss	Grazing
Raccoon	*Procyon lotor*	Forest-field edges in Illinois	Habitat fragmentation	Reduce nesting songbirds	Predation
White-tailed deer	*Odocoileus virginianus*	Forest	Predator removal	Alter plant diversity	Grazing
Plants					
Grasses	*Calamagrostis canescens*	Wetlands	Increased atmospheric nitrogen and terrestrialization	Alter community structure	Colonization
	Brachypodium pinnatum	Chalk grassland	Prevent succession and increased nutrients	Reduce diversity	Competition
	Molinia caerulea	Wetlands	Increased atmospheric nitrogen	Alter community structure	Competition
	Brachypodium pinnatum	Chalk grassland	Increased soil nitrate	Reduce diversity	Competition
	Elymus spp	Salt marsh	Increased atmospheric nitrogen	Reduce diversity	Competition
	Elymus athericus	Salt marsh	Increased atmospheric nitrogen	Alter community structure	Alter nutrient recycling
Broom snakeweed	*Gutierrezia sarothrae*	Semi-arid rangelands	Grazing and fire suppression	Alter community structure	Colonization
Common reed	*Phragmites australis*	Salt marsh	Shoreline development	Reduce richness	Competition for nutrients
Fern	*Dennstaedtia punctilobula* Michx	Forest	Deer browsing	Inhibit tree regeneration	Light limitation
	Dennstaedtia punctilobula Michx	Hardwood forest	Deer browsing	Alter community structure	Competition for light
Cattail	*Typha* spp	Coastal wetlands	Dikes	Alter community structure	Competition
Prickly lettuce	*Lactuca serriola*	Temperate grasslands	Unknown	Alter community structure	Unknown
Liana	*Vitis* spp	Floodplain forest	Temperature, atmospheric chemistry, fire suppression	Alter community structure	Competition/structural parasites
		Hardwood forest	Fire suppression	Alter community structure	Competition/structural parasites
		Amazonian forest	Increased atmospheric carbon dioxide	Alter community structure	Competition/structural parasites
		Neotropical forests	Increased atmospheric carbon dioxide	Alter community structure	Competition/structural parasites
Shrubs	*Alnus alnobetula,*	Sub-alpine grasslands	Land abandonment	Reduce richness	Competition
	Zanthoxylum americanum	Floodplain	Modified flood regime	Alter community structure	Competition
Juniper	*Juniperus occidentalis*	Sagebrush	Fire suppression and livestock	Alter vegetation structure	Competition
Woody plants	*Prosopis* spp, *Larrea* spp	Perennial grasslands	Desertification	Reduce grassland	Reduce water
Douglas-fir	*Pseudotsuga menziesii*	Mountain sagebrush–grassland	Fire suppression	Homogenization of vegetation	Competition
Red maple	*Acer rubrum* L	Deciduous forest	Fire suppression	Alter community structure	Alter nutrient recycling

Notes: Human-mediated processes allow native species to become invasive through a variety of mechanisms. Refer to WebTable 1 for associated references.

Intentional stocking provides the mechanism for native species to invade new areas within their native range (range-filling native invasion) or to supplement existing populations (dominant native invasion). The economic value of recreational fisheries only serves to place further pressure on resource managers to increase the distribution and abundance of game species regardless of harmful effects (Acevedo and Cassinello 2009). For example, rainbow trout (the resident life-history form of *Oncorhynchus mykiss*; Panel 1), a popular sport fish and among the most widely introduced fishes worldwide, may have the highest propagule pressure of any vertebrate (Fausch 2007). When stocked into new systems within their natural range, which includes the US Pacific Coast (from Alaska to Mexico) and the eastern coast of Asia, rainbow trout inflict invasive ecological impacts, including the extirpation of native amphibians (eg Knapp *et al.* 2001). For example, from 1918 until 1973, the US National Park Service stocked rainbow trout in fishless lakes in Mt Rainier National Park in Washington State (Figure 1). These stocked trout devastated native food webs by causing a trophic cascade, and primary producers (diatoms) have yet to recover in these lakes, even decades after fish removal (Drake and Naiman 2000). By consuming emerging aquatic insects, rainbow trout introduced to fishless lakes in other regions have altered lake-derived resources to passerine birds (Epanchin *et al.* 2010) and river-derived resources to terrestrial spiders (Baxter *et al.* 2004). In addition, management agencies regularly supplement existing rainbow populations with larger individuals to artificially enhance density and/or size structure, resulting in elevated competition with and predation on other native species. Apart from a few well-studied systems (eg Drake and Naiman 2000), data are not readily available to compare the current rainbow trout distribution and abundances with historical patterns throughout the PNW. Stocking rainbow trout also creates genetic concerns for wild trout; introgression (gene flow from one species into another species or subspecies by hybridization and backcrossing) of hatchery-origin rainbow trout with wild populations may reduce the fitness of the wild populations (Allendorf *et al.* 2005). In areas of the US Mountain West where rainbow trout are non-native, rainbow trout hybridizing with west slope cutthroat trout (*Oncorhynchus clarkii*) expedite the extinction of cutthroat trout through introgression (Muhlfeld *et al.* 2009). Within the Mountain West, one species – *O mykiss* – is simultaneously a stocked native invader (rainbow), a threatened species (steelhead, the anadromous life history of *O mykiss*), and a stocked non-

Panel 1. Examples of native invaders that interact with threatened and endangered salmon in the US Pacific Northwest, including the (a) Caspian tern (*Hydroprogne caspia*), (b) rainbow trout (*Oncorhynchus mykiss*), (c) northern pikeminnow (*Ptychocheilus oregonensis*), and (d) marine mammals, such as the California sea lion (*Zalophus californianus*), Steller sea lion (*Eumetopias jubatus*), and Pacific harbor seal (*Phoca vitulina richardsi*; pictured)

	(a) Caspian tern	(b) Rainbow trout	(c) Northern pikeminnow	(d) Marine mammals
	 T Good	 G Winans	 M Nesbit	 C Emmons
Mechanisms resulting in native invaders	*Dam construction* and *waterway dredging* created dredge spoil islands with high nesting success due to no predators and stable water levels.[1,2,3] *Fish hatcheries* provide a stable food supply.[4]	*Stocking* to new locales and supplementing existing populations to artificially enhance recreational fishing opportunities.	*Dams* and the creation of reservoir habitat has led to high abundances.[8] Dams increased the amount of rearing habitat and raised water temperatures, leading to higher predation rates.	*Fish passage ladders* at dams congregate salmonids, creating areas of high capture efficiency.
Examples of impacts from native invaders	Rice Island: 8.1 million salmon consumed in 1997 and 12.4 million salmon consumed in 1998[1] prior to mitigation. East Sand Island: over 5 million salmon consumed annually (on average) from 2000 to 2010. Crescent Island: 465 000 salmonids consumed in 2000 and 679 000 in 2001.[5]	Stocked into previously fishless lakes, thereby reducing native species.[6] Effects of supplemented populations are not available. Hybridization with wild populations or other salmonids.[7]	Example of salmon losses (in millions): Bonneville 1.0; Dalles 2.3; John Day 1.2; McNary 0.6; Priest Rapids 0.2; Wanapum 0.2; Rock Island 0.5; Rocky Reach 0.2; Wells < 0.1; Ice Harbor < 0.1; Lower Monumental 0.1; Little Goose 0.2; Lower Granite 0.1.[9]	Sea lions and harbor seals consumed ~4960 salmon (2.7% of the salmon run) at the Bonneville Dam in 2009.[10]
Public perception	Mixed	Positive	Negative	Mixed
Current management	Shrink and relocate colony[1]	Stocking and fishing regulations	Angler reward program and trapping	Physical barriers, hazing, and relocation[10]

Notes: [1]Roby *et al.* (2003); [2]Collis *et al.* (2002); [3]Wiese *et al.* (2008); [4]Suryan *et al.* (2004); [5]Antolos *et al.* (2005); [6]Drake and Naiman (2000); [7]Muhlfeld *et al.* (2009); [8]Zimmerman and Ward (1999); [9]Re-created from Table 1 in Beamesderfer *et al.* (1996); [10]Stansell *et al.* (2009).

native, partially responsible for decreasing populations of a native species (west slope cutthroat), all depending on location. This example illustrates the difficulties of conducting research on native invaders where studies and findings may only apply to distinct locations within a relatively small geographic region.

Once a native species transitions to invader status, quantifying the impacts on populations, communities, and ecosystems poses new challenges. The impacts of native invaders are not well documented, even among high-profile species like the threatened and endangered Pacific salmonids (Sanderson *et al.* 2009). Quantifying the threat of native invaders on salmonids requires knowledge of population size and per-capita effects (eg diet and foraging behavior data) for the native invasive species and, simultaneously, data on the population dynamics of salmonids. In some species-specific cases – such as that of the Caspian tern – state, federal, and academic researchers have invested substantial resources toward understanding the ecological impacts (BRN 2011). Because of this continuing effort, we know that Caspian terns can consume up to 15% of juvenile ESA-listed salmon populations in the Columbia River estuary (Roby *et al.* 2003). Annual consumption of salmon smolts by Caspian terns averaged over 5 million from 2000 to 2010 at East Sand Island in the Columbia River estuary (Figure 1; BRN 2011). Substantial reliance on salmonids for prey prompted managers to relocate tern colonies to a natural island (although one greatly modified by human activities) near the mouth of the river, with closer access to marine forage fish (Roby *et al.* 2002). To further minimize predation, managers are enticing tern populations to colony sites in interior Oregon and California's San Francisco Bay area (USFWS [2006] and references therein). Managers do not always have the option of relocating individuals. Control efforts for a native invader often target population size by reducing fertility, such as in the use of contraceptives for elk (*Cervus elaphus*) in Rocky Mountain National Park (Table 1). If mitigation efforts are effective, a final scientific problem is to determine when a native species is no longer considered an invader. To our knowledge, there are no examples of removing invader status in the scientific literature.

■ Management challenges

Perhaps the greatest management difficulty associated with native invaders arises from policy decisions that are often constrained to treat the symptoms as opposed to the root cause of a native species becoming an invader (Goodrich and Buskirk 1995). For example, the native northern pikeminnow (*Ptychocheilus oregonensis*; Panel 1) became an invader as a result of expanded populations and high predation rates on juvenile ESA-listed salmon in the Columbia River Basin (Figure 1). In response, the northern pikeminnow is managed through trapping and an angler reward program aimed at culling larger individuals, to lower population density and alter size structure, thereby reducing predation rates (Zimmerman and Ward 1999). The reward program, initiated in 1991, pays anglers between \$4 and \$8 per fish, with individual anglers making over \$55 000 in a single year (Northern Pikeminnow Sport-Reward Program 1998–2009). The program is popular with participants because it provides recreational opportunity, some financial benefit, and a positive psychological reward for involvement in a salmon enhancement program. From 1998 to 2009, anglers harvested more than 2.2 million northern pikeminnow, resulting in nearly \$14 million in rewards paid (Northern Pikeminnow Sport-Reward Program 1998–2009). Overall, the program is believed to have reduced predation on juvenile salmonids by targeting northern pikeminnow larger than 250 mm in total length, but estimates vary widely (Zimmerman and Ward 1999). Although reducing northern pikeminnow in the Columbia River Basin and being more cost-effective than if management agencies conducted the entire control effort, the reward program fails to address the streamflow regulation and impoundments created by the hydropower system that is causing the problem, and that continues to support invasive levels of pikeminnow. The issue of native invaders preying on imperiled species exists in other ecosystems as well. For instance, the lethal removal of barred owls (*Strix varia*) to reduce predation on the ESA-listed northern spotted owl (*Strix occidentalis caurina*) is presently under consideration in old-growth forests of Oregon and Washington (Livezey 2010). However, reducing barred owl abundances does not address the forestry practices that have led to their range expansion.

Inconsistent mitigation strategies among various species that consume salmonids in the Columbia River system result in part from public sentiment toward certain charismatic species (Panel 1). As mentioned above, anglers willingly remove northern pikeminnow, whereas marine mammal native invaders (Pacific harbor seals [*Phoca vitulina richardsi*], California sea lions [*Zalophus californianus*], and Steller sea lions [*Eumetopias jubatus*]; Panel 1) are currently managed by non-lethal methods (Stansell *et al.* [2009] and references therein). Marine mammals are protected from lethal removal by both public sentiment and firm regulatory drivers in the Marine Mammal Protection Act (MMPA), with additional safeguards for Steller sea lions under the ESA; however, regulations affecting marine mammals have shifted over time. Until 1960, a bounty on harbor seals in Oregon, Washington State, and British Columbia, Canada, was instituted in response to demands from fishermen, thus reducing the number of salmon lost to predators and protecting commercial fisheries (Jefferies *et al.* 2003). Subsequent data demonstrated that this management approach put populations of marine mammals in jeopardy, thus ending the program. Marine mammal populations have since rebounded; for example, harbor seal populations in Washington State and along the Oregon coast have steadily increased since passage of the 1972 MMPA, leading to populations stabilizing in the 1990s (Jefferies *et al.* 2003; Brown *et al.* 2005). Greater numbers of California sea lions, harbor seals, and Steller sea lions have also ventured farther up the Columbia River (Brown *et al.* 2005). Annually, these mammals swim through the Lower Columbia River up to the Bonneville Dam (river mile 146; Figure 1), where they prey on adult salmon grouping below the dam, near the fish ladders. In recent years, managers have deployed a suite of actions to deter marine mammals from foraging below the dam, including physical barriers, acoustic deterrents (eg underwater percussion devices), above-water pyrotechnics, harassment (eg boat chasing, rubber bullets), and relocation (Stansell *et al.* 2009). Along the Columbia River, the fewest marine mammal sightings were recorded in 2009, yet concurrent estimates suggest the highest consumption of salmon by marine mammals occurred during that year (Stansell *et al.* 2009). This discrepancy leads to questions about the effectiveness of marine mammal deterrents in terms of reducing salmon predation. The management strategy for marine mammals remains volatile, as a decision in March 2008 led to the lethal removal of 40 California sea lions from the Bonneville Dam. The Humane Society of the United States and the Wild Fish Conservancy challenged the lethal removal, resulting in the Ninth Circuit Court of Appeals (23 Nov 2010) reversing the earlier decision of the US District Court granting authority to the National Marine Fisheries Service to allow states to lethally remove sea lions (*Humane Society v Locke 2010*). The decision prohibiting lethal removal was predicated on an inability to link a negative impact from marine mammal predation to the recovery of ESA-listed salmonids. This example underscores how management decisions can become highly controversial when dealing with charismatic species as opposed to species that the public does not care about, such as the pikeminnow. Charisma and recreational value often drive management strategies due to societal pressures (see section below; Panel 2).

A question common to invasive species, native or non-native, is whether control programs effectively mitigate impacts (Shine and Doody 2011). In the Columbia River Basin, there is a need for further open debate among researchers, managers, and policy makers on the effectiveness of past and current mitigation strategies for native invaders. Validating the efficacy of the Northern Pikeminnow Sport-Reward Program (Zimmerman and Ward 1999), an avian predator control program (Wiese *et al.* 2008), and deterrents for marine mammals (Stansell *et al.* 2009) is an ongoing process. However, specific questions must be asked regarding each mitigating action, such as: do predator reductions improve juvenile salmon survival at the basin-wide scale, or only provide site-specific benefits? Could a management program be better directed at areas identified as key predation zones? Are there unintended consequences of any management actions to control native invaders, such as promoting existing invasive species and their impacts? Moreover, a management action designed to reduce population size may have non-linear or indirect effects that negate the desired effect or create new issues. For example, concern over gulls (*Larus* spp) consuming juvenile salmon migrants in the mid-Columbia River (Crescent Island; Figure 1) has prompted discussion

Panel 2. Management of a native species (northern pikeminnow) and a non-native species (smallmouth bass) in the US Pacific Northwest

Smallmouth bass (*Micropterus dolomieu*; Figure 2), introduced into the Pacific Northwest (PNW) in the 1920s as a sport fish, are now one of the most widely dispersed non-native fish in the PNW (Sanderson *et al.* 2009; Carey *et al.* 2011). Smallmouth bass thrive in reservoir habitats – with slow backwaters, warmer temperatures, and higher water clarity – created by dams along the Columbia and Snake rivers. As omnivorous top predators, smallmouth bass forage on native invertebrates (eg crayfish) and several native fish (eg *Cottus* spp), including juvenile Pacific salmon (Carey *et al.* [2011] and references therein). In fact, smallmouth bass prey extensively on juvenile salmon, with high numbers consumed at specific sites and large percentages of juvenile salmon runs lost to bass predation (Sanderson *et al.* 2009).

Figure 2. *A male smallmouth bass guarding its nest in Oregon's John Day River.*

As a popular sport fish, smallmouth bass make up a substantial percentage of the recreational freshwater fishery in the PNW (Carey *et al.* [2011] and references therein). High numbers of anglers targeting smallmouth bass result in millions of angler fishing days per year and a large contribution to local economies. The high monetary value of the recreational fishery and the lobbying power of the very popular bass-angling clubs (eg The Bass Federation and BASS) have led resource managers to focus on maintaining, if not promoting, the bass fishery. Idaho, Oregon, and Washington State have angler regulations (bag and size limits) designed to maintain the smallmouth bass fishery and have stocked smallmouth bass in numerous water bodies. Ironically, though both prey on salmon, non-native smallmouth bass are promoted, whereas native northern pikeminnow (*Ptychocheilus oregonensis*) are aggressively removed. The Northern Pikeminnow Sport-Reward Program removed 3 345 708 pikeminnow from 1991 to 2009 from the Columbia and Snake rivers (Northern Pikeminnow Sport-Reward Program 1998–2009), while during that time period the states of Idaho, Oregon, and Washington combined to stock 463 269 smallmouth and largemouth bass (*Micropterus salmoides*) in water bodies throughout the PNW (Idaho Department of Fish and Game, Oregon Department of Fish and Wildlife, and Washington Department of Fish and Wildlife unpublished data). Differences in management objectives exist between native and non-native species with the same potential to adversely affect threatened and endangered salmon.

of predator control; however, Wiese *et al.* (2008) pointed out that although gulls have a small effect on salmon, consuming < 1% of juvenile migrants, they have a large effect on juvenile northern pikeminnow. Thus, reducing the population size of gulls may ultimately increase the number of northern pikeminnow available to consume salmon. In another example, populations of invasive smallmouth bass (*Micropterus dolomieu*), which predate heavily on juvenile salmonids (Sanderson *et al.* 2009; Carey *et al.* 2011), may increase in response to depressed northern pikeminnow populations that result from the angler reward program. These examples demonstrate how publishing the results of investigations into the effectiveness of mitigation strategies aids scientists in future research and allow policy makers to use peer-reviewed results to inform policy decisions (Shine and Doody 2011).

Societal challenges

Scientists and members of the public frequently disagree about the nature and magnitude of problems posed by invaders (Schlaepfer *et al.* 2011), which can directly affect management and conservation decisions (Shine and Doody 2011). This is perhaps not surprising, given that previous attempts to cull "attractive" non-native invasive species, such as gray squirrels (*Sciurus carolinensis*) in Europe, have encountered the greatest public opposition (eg Bremner and Park 2007), whereas non-native species with less appeal, such as the cane toad (*Rhinella marina*, formerly *Bufo marinus*) in Australia, have been the focus of millions of dollars and thousands of hours of community effort (eg volunteer "toad-busting" groups) to direct physical removal (Shine and Doody 2011). Public opinion toward avian predator relocation or removal falls somewhere in the middle, eliciting polarized reactions from the public; some fiercely argue for the protection of avian species, whereas others are eager to reduce populations. Indeed, the greatest hurdles are both to convince the public that a native species can be a problem and to engender broader public support for scientifically based management actions to control native species. Age, gender, and belief systems (as well as attitudes toward the taxa concerned) affect the level of opposition to lethal control programs (Dougherty *et al.* 2003), suggesting that confronting this obstacle will be no small task.

Clearly, a single species functioning as an invader in one food web, and not in another in close proximity, creates a unique education problem that does not exist for non-native invasive species. In another example, double-crested cormorants (*Phalacrocorax auritus*), like Caspian terns, have benefited from hydropower system-related habitat modifications, resulting in increased population size and reliance on juvenile salmon as prey (Collis *et al.* 2002). At the same time that cormorant populations are growing along the Columbia River and impacting ESA-listed salmon populations, cormorant colonies along the Pacific coast are declining and becoming a cause for concern about the overall status of the species in the PNW (Gewin 2011). Thus, managers decided to relocate the East Sand Island colony away from the mouth of the Columbia River instead of lethally removing the birds. The cormorant conundrum – increasing invasive populations in the Columbia Basin but decreasing populations regionally – creates both an education and management challenge.

Education and outreach to stakeholders is imperative in developing support for native invader mitigation efforts and in garnering public compliance with the removal guidelines. Media coverage influences the public perception of a species (Bremner and Park 2007). For example, intensive media coverage of a California sea lion affectionately named Herschel, which consumed salmon at the Ballard Locks of Seattle's Lake Washington Ship Canal in the 1980s (Figure 1), magnified the spotlight on marine mammal predation of salmonids. Unfortunately, this was one of many instances where the media built enthusiasm for native species control by presenting a simplified and relatively extreme view of marine mammal impacts. Similarly, media coverage of angler earnings from the Northern Pikeminnow Sport-Reward Program can reinforce the zeal for removing this native species without conveying the details of their location-specific impacts. The rules and regulations for the Northern Pikeminnow Sport-Reward Program state that its boundaries include "the mainstem Columbia River from the mouth up to the restricted zone below Priest Rapids Dam, or in the Snake River from the mouth up to the restricted zone below Hell's Canyon Dam" (Figure 1; Northern Pikeminnow Sport-Reward Program 2010). Using the media to convey the value of northern pikeminnow as an integral member of a native food web in other locations could be beneficial. Any outreach effort should also communicate how and when a species loses its native invader status. A return to a natural state is often not possible; the question thus becomes, what is socially and ecologically acceptable in each set of circumstances?

Policy challenges

Policy makers struggle to find acceptable solutions for contending with native invaders. Wildfire suppression to protect human interests, for example, has led to the expansion of juniper throughout the PNW, thereby altering hydrology and increasing erosion along streams (Ansley and Rasmussen 2005). Juniper likely affects native species, including ESA-listed salmon that inhabit these streams. In many instances, policy must balance competing human interests, leading to conflicting goals under the purview of a single state or federal natural resource agency (Clarkson *et al.* 2005). For example, native northern pikeminnow are aggressively removed to reduce salmon predation, while non-native smallmouth bass and largemouth bass (*Micropterus salmoides*), with predatory impacts similar to those of pikeminnow, are maintained or even promoted for recreational fisheries (Panel 2; Carey *et al.* 2011). In another example, Washington State stocked more than 7.8 million rainbow trout in 2006 (Washington Department of Fish and Wildlife unpublished data); the net economic value of the recreational fishery for trout was estimated at nearly $146 million (TCW Economics 2008). To date, the economic benefits of the recreational fishery have trumped concerns that rainbow trout act as native invaders (Panel 1). Researchers need to continue exploring the consequences of stocking native and non-native species (Cucherousset and Olden 2011).

Although helping to protect the ecological integrity of ecosystems, clarifying objectives and avoiding competing goals within agencies is seemingly impossible, given that state agencies like the Washington Department of Fish and Wildlife are tasked with both protecting native species and maintaining recreational fisheries for popular sport fish. For example, the stated intention of the *Warm water game fish enhancement program* is "to increase the opportunities to fish for and catch warm water game fish including: largemouth black bass, smallmouth black bass, channel catfish, black crappie, white crappie, walleye, and tiger musky" (Revised Code of Washington 77.44.010, http://apps.leg.wa.gov/RCW/default.aspx?cite=77.44.010). The same law also states that "transplantation and introduction of exotic warm water fish shall be carefully reviewed to assure that adverse effects to native fish and wildlife populations do not occur" (Revised Code of Washington 77.44.040, http://apps.leg.wa.gov/RCW/default.aspx?cite=77.44.040). Science can provide valuable information to guide policy decisions; however, policy makers need to communicate with scientists in order to make decisions under these conflicting goals. Clearly, policy conflicts will be the most contentious when they present mutually exclusive choices, pitting the scientifically supported need for control against the economic and recreational benefit of the human activity responsible for creating the native invaders.

■ Future challenges

Human alterations of ecosystems will continue to promote native species to invader status as a result of enhanced abundance, greater per-capita effects, and colonization of new habitat within their native range. By raising awareness of the ecological impacts of native invaders, scientists and policy makers can collaborate to determine acceptable or desirable management responses. For threatened and endangered species, addressing native invaders in recovery plans is one way to help prioritize threats. Interactions with native species are often documented in species recovery plans but are not always prioritized or followed by management actions according to the magnitude of their impact (Lawler *et al.* 2002). In one successful example outside the PNW, the recovery plan for loggerhead sea turtles (*Caretta caretta*) considers predation by raccoons (a native invader) on turtle eggs and hatchlings as a major threat (Bolten *et al.* 2011). Higher population sizes of raccoons due to reduced predators and increased food availability from human sources led to increased consumption of sea turtle eggs by raccoons. In response, predator removal (trapping, hunting) and nest protection programs have dramatically reduced predation by raccoons throughout the southeastern US (NMFS and USFWS 2008). Identifying threats and understanding the mechanisms that are creating these threats allows management to specify recovery tasks (Lawler *et al.* 2002). How society values each species influences management strategies and may or may not align with the ecological goals of maintaining natives and eliminating non-native species. Outreach programs must convey the spatial and temporal nuances of mitigation strategies to prevent harm to native species outside of the area in which they are invasive. Regulations – similar to the nuisance species list for non-native invaders that discourages translocation of species – would be appropriate to prevent native invader impacts. The next step for determining a quantitative threshold for native invaders would be to improve researchers' ability to identify native invaders and develop mitigation strategies. Overall, a more comprehensive view of native invaders, one that considers multiple processes and ecosystems, is necessary to improve conservation and management efforts for native species.

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