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REVIEW OF THE NEGATIVE INFLUENCES OF NON-NATIVE SALMONIDS ON NATIVE FISH SPECIES

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ABSTRACT—Non-native salmonids are often introduced into areas containing species of concern, yet a comprehensive overview of the short- and long-term consequences of these introductions is lacking in the Great Plains. Several authors have suggested that non-native salmonids negatively influence species of concern. The objective of this paper is to review known interactions between non-native salmonids and native fishes, with a focus on native species of concern. After an extensive search of the literature, it appears that in many cases non-native salmonids do negatively influence species of concern (e.g., reduce abundance and alter behavior) via different mechanisms (e.g., predation and competition). However, there are some instances in which introduced salmonids have had no perceived negative influence on native fishes. Unfortunately, the majority of the literature is circumstantial, and there is a need to experimentally manipulate these interactions.

Key Words: non-native, fish, competition, predation, review, threatened, species of concern, salmonid

INTRODUCTION

Great Plains streams represent some of the most unique and endangered freshwater systems in the world. Although these streams historically had a rich mixture of native species, several Great Plains fishes have become threatened or endangered as a result of introduced fishes, lack of suitable habitat, anthropogenic flow regime alterations, or a mixture of these factors. Here we examine the effects of introducing non-native salmonids on native fish species of concern. In many of the studies listed throughout this paper, introduced fishes are not the only contributors to declines in native populations. In most cases, effects are facilitated or amplified by habitat deterioration. Combined effects of multiple stressors on native populations can lead to further endangerment of species of concern. Mitigating all stressors is essential to the protection and recovery of these species; however, here we focus solely on influences of non-native fish species. Species of concern, as used in this paper, are defined as species that are (1) listed as threatened or endangered under

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the U.S. Endangered Species Act of 1973 (ESA), (2) listed as threatened, endangered, imperiled, or vulnerable in an individual state, (3) endemic, or (4) in need of conservation actions, which are considered vital to their survival. Anticipating potential interactions between introduced non-native fishes and fish species of concern will ensure proper conservation and management of these important species. In addition, no comprehensive review of non-native salmonid interactions with species of concern currently exists for systems like those found in the Great Plains. Therefore, the objective of this paper is to review known interactions between introduced fishes and native fishes with a focus on salmonids and species of concern.

METHODS

We reviewed primary literature focusing on the influence of non-native salmonids on native fishes. The original search included a title and abstract search of articles published in or after 1970. Original journals searched were *Ecology of Freshwater Fish*, *Fisheries*, *North American Journal of Fisheries Management*, and *Transactions of the American Fisheries Society*. Additionally, a general search using key words such as "fish species of concern," "non-native salmonids," and "impacts of non-native fishes" were used and appropriate papers were included. Relevant articles cited within papers identified in the original search were included as well.

This review is broken down into two parts. The first part is a quantitative synthesis of peer-reviewed literature examining non-native salmonid interactions with native fishes in the Great Plains (mostly experimental studies), excluding non-native salmonid and native salmonid interaction studies. The Great Plains, as used in this paper, refers to the area encompassed by North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma. However, when we examined non-native trout introductions, we expanded our search to the continental United States because species-specific information was limited in the Great Plains. We summarized the geographic area where the study took place and whether or not the study design was empirically based. We also asked which non-native and native species were involved: Did the non-native species have a significant influence on the native species, and if so, what were the influences on the native species? Were the influences positive, neutral, or negative? What biological organization levels were influenced? Were the mechanisms of the influences identified, and if so, what were the mechanisms? How much time elapsed since introduction of the non-native species? For empirical studies, what were the methods of introduction? The second part of this review is a qualitative review of papers encompassing a more global perspective, which may provide helpful insight into what may occur in the Great Plains with continued introductions of non-native salmonids.

QUANTITATIVE RESULTS

We identified 133 articles pertaining to influences of non-native sport fish introductions on native fishes. This list was reduced to 77 articles, published in over 30 peer-reviewed journals from 1972 to 2011, that more specifically examined the effects of non-native salmonid introductions. Of these, 25 were excluded from further analysis because they occurred outside the continental United States. Interactions, mostly competitive in nature, between introduced salmonids and native salmonids of concern are well studied and reviewed (Krueger and May 1991; Kruse et al. 2000; Peterson and Fausch 2003; Dunham et al. 2004; Cucherousset and Olden 2011). We therefore excluded an additional 17 articles examining these interactions from analysis.

Geographic Area. We identified only one peer-reviewed journal article that examined the influences of stocking non-native trout on native fishes in the Great Plains. Walsh and Winkelman (2004) monitored changes in a fish assemblage before and after the introduction of non-native rainbow trout (*Oncorhynchus mykiss*) in an Oklahoma stream. Although they observed a change in assemblage in some pool habitats, they were not able to definitively conclude it was the result of the introduced trout. We did find several state and federal reports, as well as some theses, from the Great Plains that suggested non-native trout introductions influence native species. However, we did not include them due to their speculative nature.

Although there is a lack of information from the Great Plains, studies of regions bordering the Great Plains provided some additional insight. The west and southwestern United States, more specifically the Colorado River system, appears to be the best-studied region. Unlike the Great Plains, these areas often constitute parts of some salmonid native ranges. Though these areas were home to salmonids historically (e.g., cutthroat trout [*Oncorhynchus clarki*]), non-native salmonids (e.g., rainbow trout) are often introduced into these areas, providing valuable insight into potential impacts of stocking non-native salmonids in areas like the Great Plains.

Study Design. Forty percent of the articles examining influences of non-native trout were classified as empirical. Studies not considered empirical were reviews, opinions, surveys, historical accounts, and those not containing a field or laboratory component. Of the empirical studies (n = 14), two were observational studies of behavior (Freeman and Grossman 1992; Olsen and Belk 2005), three included diet analyses (Marrin and Erman 1982; Marsh and Douglas 1997; Yard et al. 2011), seven manipulated interactions using in-stream enclosures or laboratory streams (e.g., Blinn et al. 1993; Rinne and Alexander 1995; Bryan et al. 2002), two introduced non-native fishes into stream reaches and monitored response in native fishes (Garman and Nielsen 1982; Walsh and Winkelman 2004), and one removed non-native fishes and monitored response in native fishes among other things (Yard et al. 2011).

Species Evaluated and Their Influence. In the empirical studies we reviewed, brown trout (*Salmo trutta*) or rainbow trout were at least one of the non-native species examined. Forty percent of empirical studies included at least one species of concern. In most cases, the non-native species did cause some change in individual behavior, prey on native species, and so forth; however, few authors specified whether or not this would have a significant impact on the population or community as a whole. The influence was always suggested to be negative or neutral, although in many cases, conclusions could be classified as speculative. In about 60% of the studies, authors at least suggest potentially negative influences of non-native species. In an additional 36% of the papers we reviewed, the authors suggested negative or neutral influences (responses often differed among different non-native species within the same study), and in only one case did authors conclude there was a neutral effect of non-native species.

Biological Organization Level and Type of Influence. Most studies observed influences on native fishes at the individual and population level; however, there were a few papers that examined community responses to non-native fishes (e.g., Walsh and Winkelman 2004). The most commonly measured influence on native species was reduction in survival or verified predation, reduction in abundance, and reduced growth. Additional influences included reduced feeding time and rate (Freeman and Grossman 1992), shifts in habitat use (Olsen and Belk 2005), and potential changes in assemblage structure (Walsh and Winkelman 2004).

Mechanism of Influence. The mechanism of the influence on native species was identified about 50% of the time. In those that examined mechanisms, predation was identified as a mechanism in approximately 80% of studies. Competition was suggested as a mechanism in about 20% of cases.

Time since Introduction. Over 70% of the studies stocked non-native trout into enclosures, laboratory streams, or stream segments as treatments. Therefore, the majority of the time these studies were examining the immediate effects of introductions, and long-term consequences of introductions were not evaluated. Methods of introduction other than experimental introduction included stocking for recreational purposes and accidental introductions.

QUALITATIVE RESULTS

The second part of this review is a qualitative review covering a broader range of papers, which may provide helpful insight into what may occur in the Great Plains with continued introductions of non-native salmonids. Here we also included international papers as well as papers discussing non-native salmonid interactions with native salmonids, which we felt provided pertinent information to managers considering stocking non-native salmonids in the Great Plains.

The potential effects of non-native salmonids may be expressed at one or several levels of biological organization (Cambray 2003; Simon and Townsend 2003; Dunham et al. 2004; Cucherousset and Olden 2011). Here we explore the range of possible effects on fishes and the mechanisms that might influence changes.

Individual. Influences of non-native salmonids can change individual behavior, diet, habitat use, fitness, and daily and seasonal movements of species of concern. Studies of alterations in habitat use and behaviors, or displacement of native species following the addition of non-native salmonid species, are prevalent in the literature (Blinn et al. 1993; Taniguchi et al. 2002; Olsen and Belk 2005; McHugh and Budy 2006; Blanchet et al. 2007; McGrath and Lewis 2007; Kadye and Magadza 2008; Penaluna et al. 2009). Salmonid introductions can also result in shifts in diet or decreases in foraging efficiency of native species (Taniguchi et al. 2002; McHugh and Budy 2006; Kayde and Magadza 2008), which may lead to decreased growth in the presence of non-native salmonids (Taniguchi et al. 2002; Ruetz et al. 2003; McHugh and Budy 2006; Blanchet et al. 2007; Zimmerman and Vondracek 2007;

Pardo et al. 2009). Presence of brown trout decreased growth, shifted habitat use, and changed behavior of native brook trout (*Salvelinus fontinalis*) in an artificial stream channel (Dewald and Wilzbach 1992). Similarly, survival rates of native chinook salmon (*Oncorhynchus tshawytscha*) were greater in streams without non-native brook trout than in streams with brook trout, although the underlying mechanisms were not examined (Levin et al. 2002). Impacts specifically on species of concern have also been recorded. Threatened Little Colorado spinedace (*Lepidomeda vittata*) changed habitat use and behavior in the presence of non-native rainbow trout (Blinn et al. 1993). Not all the above-listed interactions have proven detrimental, yet any change in normal behavior could be of concern, as it may lead to decreased fitness.

Introduced non-native chinook salmon had little effect bioenergetically on native brook trout even though they significantly increased short-term brook trout movements in Michigan streams (Janetski et al. 2011). Non-native trout and tui chub (*Gila bicolor*) successfully partitioned resources and avoided competition in a California reservoir (Marrin and Erman 1982). In the presence of rainbow trout and brown trout, some native species (*Brachygalaxias bullocki*, *Galaxias maculates,* and *Trichomycterus areolatus*) demonstrated changes in habitat use, while other native species (*Geotria australis*) were unaffected due to differences in niche overlap (Penaluna et al. 2009). Size-selective predation led to an increase in size of individual dace (*Phoxinus* spp.) in lakes stocked with non-native salmonids compared to those that were not stocked (Nasmith et al. 2010). Similarly, non-native brook trout did not appear to affect the condition of adult greenback cutthroat trout (*Oncorhynchus clarkia stomais*) in Colorado streams (McGrath and Lewis 2007).

Population. Abundance is the most commonly observed and measured response of native populations to non-native salmonids. Several studies have attributed the declines in abundance of native fishes (Arismendi et al. 2009) and threatened native fishes (Rinne and Alexander 1995) to the introduction of salmonids. Abundance of native spotted galaxias (*Galaxias truttaceus*) in Tasmanian streams was explained better by the presence of non-native brown trout than by habitat and was lower in the presence of trout than expected based on habitat alone. Similarly, brown trout was the best predictor of presence and abundance of native *Galaxias vulgaris* in New Zealand catchments (i.e., *Galaxias vulgaris* presence was best predicted by brown trout absence; Townsend and Crowl 1991). Conversely, Nasmith et al. (2010) saw that although introduced trout (brook, rainbow, and brown trout) caused a shift in habitat use of native dace in Alberta ponds, trout had no overall effect on the population density of the dace.

Community. Introduced non-native fishes can affect species richness, composition, and size distribution of native communities as well as alter food webs. These changes have been recorded for numerous introduced fishes but are less well known for introduced salmonids. Walsh and Winkelman (2004) reported a shift in fish assemblage in pools in an Oklahoma stream. Assemblage changes included a decline in seven species following the introduction of rainbow trout (Walsh and Winkelman 2004). Flecker and Townsend (1994) saw decreases in insect density and biomass that resulted in increased algal growth in the presence of non-native brown trout. Konishi et al. (2001) found that the presence of rainbow trout and freshwater sculpin (*Cottus nozawae*) reduced foraging activity of the dominant amphipod (*Jesogammarus jezoensis*) and thus influenced stream leaf litter processing efficiency.

Ecosystem. Alterations in food webs, nutrient cycles, and physical habitats can result from introductions (Eby et al. 2006). Introductions of non-native rainbow trout to Japanese streams caused a shift in the diet of native dolly varden (*Salvelinus malma*) (Baxter et al. 2004, 2007). The shift in diet of dolly varden in turn caused a decrease in herbivorous insects and a corresponding increase in algal growth. The decrease in insect abundance, and thus emergence, resulted in lower aquatic to terrestrial flux and a reduction in riparian spiders (Baxter et al. 2004, 2007). Similar ecosystem-level influences of non-native trout may occur in Great Plains streams with historically simple community structures. For example, the headwater community of a typical Great Plains stream may consist of a few species of drift-feeding cyprinids and some benthic-feeding catostomids. Introduction of drift-feeding rainbow trout could likely reduce the abundance of invertebrates available for cyprinids. Cyprinids may then shift to a more benthic diet, and therefore also influence catostomid food resources. Increased benthic feeding may then result in alterations to the benthic macroinvertebrate community, which could have ramifications throughout the food web. In Great Plains communities, characteristic low diversity may amplify the effects of introductions, because the presence of fewer trophic levels means that effects cascade through the system at a more direct and rapid rate than in more complex systems.

Mechanisms that Affect Native Species of Concern

There are four main mechanisms by which salmonids can negatively affect species of concern: predation, competition, hybridization, and disease transmission. Several local, state, and federal agencies have warned against the potential negative interactions between non-native salmonids and native fishes. Each mechanism is reviewed below.

Predation. Direct non-native salmonid predation on several native fish species of concern has been documented (see review Taylor et al. 1984). Many studies have theorized that predation has contributed to the decline of species of concern, but here we discuss only those where direct predation has clearly been documented through observation, experimental studies, or diet analysis. Salmonid predation has been validated on endangered razorback suckers (*Xyrauchen texanus*) (Carpenter and Mueller 2008), endangered humpback chub (*Gila cypha*) (Marsh and Douglas 1997), threatened Little Colorado spinedace (Blinn et al. 1993; Rinne and Alexander 1995), and threatened *Galaxias auratus* (Stuart-Smith et al. 2007). Yard et al. (2011) confirmed rainbow trout and brown trout predation on several native Colorado River species including the endangered humpback chub. The trout consumed a much greater proportion of native fish than non-native fish despite the greater abundance of non-native fishes in the river (Yard et al. 2011).

Although there are few instances of salmonid predation on species of concern, predation on the same or similar species in areas where their populations are considered stable has been documented. For example, stocked brown trout greater than 280 mm consumed native nongame species 25 mm to 110 mm in length in a Virginia creek (Garman and Nielsen 1982). Among these, the three most commonly consumed species—torrent sucker (*Moxostoma rhothoecum*), roseyside dace (*Clinostomus funduloides*), and central stoneroller (*Campostoma anomalum*)—are morphologically similar in size and shape (e.g., fusiform bodies, soft rayed fins) to many dace species of concern in the Great Plains. Brown trout were also found to be piscivorous at 130 mm (L'Abee-Lund et al. 1992) and found to consume *Phoxinus phoxinus*, an abundant cyprinid species in Norway (L'Abee-Lund et al. 2002). Similarly, East and Magnan (1991) found redbelly dace (*Phoxinus eos*) can comprise up to 30% by weight of brook trout diets in Ontario lakes. In the United States, *Phoxinus* species are listed as species of concern in several states including Great Plains states, and two members of the genus *Phoxinus* are federally listed as threatened and endangered (Williams et al. 1989). Stocking of non-native salmonids may be of concern, as these species are often found in preferred salmonid habitat, and introduction could result in increased predation risk.

Non-native piscivores may pose an increased risk to native populations due to a lack of coevolutionary history resulting in the inability of native fish to recognize non-native fish as a threat (Townsend and Crowl 1991; Blinn et al. 1993; Bryan et al. 2002; Nannini and Belk 2006). This is a potential reason introduced rainbow trout were able to easily prey on Little Colorado spinedace even in the presence of increased cover (Blinn et al. 1993). Bryan et al. (2002) also suggested that spinedace decreased activity in the presence of non-native rainbow trout due to an inability to recognize them as a threat. Lack of coevolutionary history suggests some adaptations, such as color, may pose increased risk of predation. Many small cyprinid species are sexually dimorphic and display bright breeding colors that can be retained far beyond the breeding season. These colors may attract or increase the probability of visible detection by introduced sport fishes such as salmonids.

It is unclear whether non-native salmonids will have an impact on the overall population of native species even if salmonids do prey on native species. Rainbow trout predation on native fishes in an Oklahoma Ozark stream was low and probably did not constitute a significant impact on the population (Walsh and Winkelman 2004). Some predation by brook trout on greenback cutthroat trout was observed in Colorado streams, but again, it probably had little effect on the greenback cutthroat trout population (McGrath and Lewis 2007). However, the magnitude of the impact of predation is amplified in threatened fishes (Knight and Gido 2005). Even if a predator randomly selects prey, the overall effect on a population will be greater for threatened or endangered species due to their already low numbers. For this reason, the possibility of predation by non-native salmonids should be of concern for threatened and endangered species.

Competition. Competitive interactions with non-native trout are often cited as possible causes of declines in abundance, species richness, and fitness, and changes in distribution, behaviors, and life histories of native species (McIntosh et al. 1994; Gido and Propst 1999; Taniguchi et al. 2002; Ruetz et al. 2003; Baxter et al. 2004; Olsen and Belk 2005; Baxter et al. 2007; Kadye and Magadza 2008; Penaluna et al. 2009). Few studies, however, have been able to provide evidence of interspecific competition between non-native salmonids and native species in natural streams (Fausch 1988). The lack of evidence for competition is because of the relatively difficult task of proving competition. Although empirical evidence is apparently lacking, there is circumstantial evidence of direct and indirect competitive interactions.

Direct competitive interactions in this case include both exploitative and interference competition. When introducing non-native salmonids, the potential for direct competitive interactions with native species due to shared habitats and diets should be of concern. Competition for space between natives and introduced species has been suggested to lead to declines in native fish populations (McIntosh et al. 1994; Gido and Propst 1999; Taniguchi et al. 2002; Olsen and Belk 2005; Kadye and Magadza 2008; Penaluna et al. 2009). Proving diet competition remains difficult, as diet overlap does not guarantee competition. However, it is still helpful to recognize potential sources of competition for food resources that may lead to the decline of a species. For example, *Gammarus pseudolimnaeus* consumption by brown trout may lead to competitive interactions between the introduced trout and native slimy sculpin *Cottus cognatus*, also a predator of G. *pseudolimnaeus* (Ruetz et al. 2003). Johnson and Johnson (1982) documented diet overlap between brook trout, blacknose dace (*Rhinichthys atratulus*), and pearl dace (*Semotilus margarita*) in a small Adirondack stream, and although they did not examine competition, they did confirm diet overlap with native species, which should caution future stockings where the dace are found. Both blacknose dace and pearl dace are found in parts of the Great Plains where non-native salmonids have been stocked. Salmonids are omnivorous and generalists, and the potential for diet overlap with these and other species of concern is present.

Although competitive interactions are likely in many areas, non-native salmonids and native fishes may successfully partition resources with no observable negative impacts. Most often this occurs in lakes where salmonids prefer deeper, cooler, more pelagic areas, and small-bodied native fishes prefer shallower, warmer, more littoral areas. Little competition between introduced trout and native species in Ontario lakes was observed because native species were isolated from trout during crucial periods due to thermal preferences (MacRae and Jackson 2001). Similarly, trout (brown trout and rainbow trout) and tahoe suckers (*Catostomus tahoensis*) occupied different areas in a California reservoir, thus potentially reducing diet overlap (Marrin and Erman 1982). In the same study, small trout and tui chub occupied similar habitats but successfully partitioned resources, making coexistence possible (Marrin and Erman 1982).

Size (Griffith 1972) and age structure (Peterson et al. 2004) may also play a role in the ability of introduced salmonids to outcompete native species. Age-1 masu salmon (*Oncorhynchus masou*) in Japan were superior competitors compared to age-0 rainbow trout, but age-1 rainbow trout competitively decreased growth and foraging efficiency of native age-0 masu salmon (Taniguchi et al. 2002). Adult greenback cutthroat trout were unaffected by brook trout, but the population was instead limited by interactions between brook trout and age-0 greenback cutthroats (McGrath and Lewis 2007). Likewise, brook trout may affect the survival of juvenile, but not age-2 or older Colorado River cutthroat trout (Peterson et al. 2004). Changes in diet, habitat use, and behaviors with ontogeny may result in differing competitive interactions among age groups. Therefore, examining all age groups is of the utmost importance (Peterson et al. 2004).

Introduced salmonids can also create competition between two normally co-occurring native salmonids. Hasegawa and Maekawa (2006) showed that in the absence of rainbow trout, white-spotted charr *Salvelinus leucomaenis* and masu salmon partitioned habitat successfully. However, when brown trout or rainbow trout were introduced, interspecific competition between the two native species increased (Hasegawa and Maekawa 2006).

Indirect competitive interactions are also of concern. The overall results of cascading effects from salmonids on native species of concern have not been well studied. However, cascades themselves are well documented, and potential impacts on native species can be implied. Flecker and Townsend (1994) examined differences in community responses to non-native and native fishes, finding that density and biomass of insects were lower in the presence of non-native brown trout relative to control treatments. This suggests introduced salmonids may reduce food resources for native fishes, leading to increased risk of competition in food-limited areas.

Most studies that investigated competitive interactions between native and non-native fishes reported harm to native fishes; however, established fishes (either native or non-native) can also outcompete introduced fishes (Weber and Fausch 2003). This may be especially true in the case of hatchery-raised sport fishes. Stream stocking often results in high initial mortality of stocked trout. Some researchers have suggested this is due, at least partially, to the superior competitive abilities of established fishes compared to hatchery-raised fishes (Miller 1958).

The species or population first established in an area tends to have the competitive advantage over newly introduced fishes (Miller 1958; Glova and Field-Dodgson 1995; Deverill et al. 1999; Harwood et al. 2003), and in some cases hatchery-raised fishes may be at a disadvantage behaviorally, physiologically, or morphologically compared to native fishes (Weber and Fausch 2003). This may produce a bias in the literature toward not reporting instances where hatchery stockings were not successful. If stockings are unsuccessful because stocked salmonids have low survival rates, interactions between native species and introduced species are likely to go unrecorded (e.g., the stocking was not successful), whereas if the natives are the ones being outcompeted, it may be more likely to be recorded.

Hybridization. Although not a concern in the Great Plains due to a lack of native salmonids, hybridization is a common mechanism by which non-native salmonids influence native fishes. Examples of negative impacts of hybridization between introduced salmonids and native fishes are abundant, as many salmonid species readily hybridize with each other. Non-native brook trout have been shown to hybridize with native brown trout, potentially reducing brown trout reproductive success in France (Cucherousset et al. 2008). Similarly, in the United States, non-native brown trout reduce native brook trout fitness through hybridization (Leary et al. 1983). Hybridization is also a concern for at-risk species and has been cited in the decline of several threatened and endangered species. Hybridization of native salmonids with non-native salmonids, especially rainbow trout, has been implicated in the decline of threatened westslope cutthroat trout *Oncorhynchus clarki lewisi* (Allendorf et al. 2004) and in the elimination of threatened Paiute cutthroat trout *Oncorhynchus clarki seleniris* from historic habitat (USFWS 2004). Non-native salmonids were considered a factor in the decline of native Apache trout (*Oncorhynchus apache*) in Arizona (Carmichael et al. 1993; Rinne and Alexander 1995) and Gila trout (*Oncorhynchus gilae*) in New Mexico (review USFWS 2002a), and were listed as a primary threat to California golden trout (*Oncorhynchus mykiss aguabonita*) (USFWS 2002b) and Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis*) (Pritchard and Cowley 2006). Additionally, non-native brook trout have been shown to hybridize with native threatened bull trout (*Salvelinus confluentus*) in the western United States (Leary et al. 1983).

There is a negative connotation associated with hybridization, especially between two distinct species. Hybridization has been shown to increase risk of extinction in threatened species and often results in a reduction or loss of genetic integrity (Cucherousset and Olden 2011). However, the negative implications are less clear when it comes to hybridization between two subspecies or even two populations of the same subspecies. Introduced species could be used in some cases to "rescue" endangered native strains of some fish species of concern through intentional hybridization, as has been done for some mammals (Land and Lacy 2000; Allendorf et al. 2004).

Disease and Pathogens. Disease and pathogen transfer is always a concern when new species are introduced. Many diseases have been introduced with the arrival of non-native fishes (Hoffman and Schubert 1984; Krueger and May 1991) and have negatively influenced native populations. Viral hemorrhagic septicemia (VHS) was first recorded in the Great Lakes basin in 2005 (although it was recorded previously in some coastal areas) and is easily transferred from fish to fish (Bowser 2009). Intense precautionary methods are underway to further prevent the spread of the disease. Both brown and rainbow trout are listed under the Viral Hemorrhagic Septicemia Federal Order, which now regulates interstate and international movement of species in VHS-infected areas (Bowser 2009). Because of this order, there is little chance of known infected individuals being stocked in uninfected areas; however, accidental introductions or intentional introductions by anglers unaware of the disease are still a concern (Bowser 2009). Aside from VHS, salmonids are also susceptible to infectious hematopoietic necrosis (IHN) and can transfer it to native populations. First recorded in the United States in the 1950s, IHN continues to threaten hatchery and wild stocks (CFSPH 2007). It can be spread between individuals via contact with infected excretory products or through infected water and often results in mortality of young fish (CFSPH 2007). Young fish mortality can reach 95%, but mortality decreases with age as resistance to infection builds (CFSPH 2007). Introductions of non-native fishes have potentially harmful effects on native fishes via disease transmission if care is not taken to ensure introduced fish are disease free.

Species-Specific Mechanisms and Potential Benefits of Non-Native Species

Introduced trout species can affect native fish species in various ways. Garman and Neilsen (1982) and Crowl et al. (1992) both suggested that brown trout are more detrimental to other fishes than rainbow or brook trout.

This may be due to the brown trout's more piscivorous nature, lower susceptibility to angling, more aggressive behavior, and greater survival rates (Garman and Neilsen 1982). However, the higher perceived risk of brown trout compared to other trouts may be due to differences in the mechanisms that ultimately influence the native species (Crowl et al. 1992). As Crowl et al. (1992) point out, hybridization is the most common mechanism by which rainbow trout influence native fishes in the United States (due in part to the large number of salmonid-salmonid hybrids), whereas predation is the most often cited mechanism of brown trout impacts. Brook, brown, and rainbow trout, however, are all capable of predation, competition, and hybridization, and where introduced, could potentially negatively interact with native species. The relative importance of these mechanisms depends on both the native and non-native species present as well as other environmental factors and resource availability.

Species of concern may also benefit from introduced salmonids. The growth and condition of some native species have benefited from the consumption of introduced salmonids' eggs. Janetski et al. (2011) observed that energy lost from increased movements of brook trout following non-native chinook salmon runs was offset by that gained from consumption of the introduced salmonids eggs. Similarly, native brook trout diets were comprised of 95.6% salmon eggs during October salmon spawning runs (Crawford 2001) and condition factor increased significantly as a result in a Lake Ontario tributary (Johnson and Ringler 1979). Non-native salmon eggs may be an especially important food source during times of the year in which resources would normally be diminished.

SUMMARY

Non-native species do interact with native species via predation, competition, and hybridization and can have both positive and negative effects. There seem to be more recorded cases of negative interactions, but there may be some bias associated with published studies that show an impact as opposed to those that show no impact, especially for species of concern. Much of the literature we reviewed was highly circumstantial in concluding that non-native salmonids had any effect on native fishes. Nonetheless, these studies lend helpful insight into what may be occurring, and should be considered before potential introductions are made. Specific interactions and consequences of introductions should be investigated prior to any introduction.

We agree with many others that there is an apparent lack of empirical evidence evaluating influences of non-native fishes on native fishes (Fausch 1988; Shafland 1996). This is especially so in the Great Plains. This lack of information emphasizes the need to gain a better understanding of how non-native fishes influence at-risk species. Exhibiting caution when proposing such introductions is a prudent approach to ensure that negative, long-term, and irreversible outcomes are prevented until the specific outcomes from such activities can be determined.

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REFERENCES

Allendorf, F.W., R.F. Leary, N.P. Hitt, K.L. Knudsen, L.L. Lundquist, and P. Spruell. 2004. Intercrosses and the U.S. Endangered Species Act: Should hybridized populations be included as westslope cutthroat trout? *Conserv. Biol.* 18:1203–13.

Arismendi, I., D. Soto, B. Penaluna, C. Jara, C. Leal, and J. Leon-Munoz. 2009. Aquaculture, non-native salmonid invasions, and associated declines of native fishes in northern Patagonian lakes. *Freshwater Biol.* 54:1135–47.

Baxter, C.V., K.D. Fausch, M. Murakami, and P.L. Chapman. 2004. Fish invasion restructures stream and forest food webs by interrupting reciprocal prey subsidies. *Ecology* 85:2656–63.

Baxter, C.V., K.D. Fausch, M. Murakami, and P.L. Chapman. 2007. Invading rainbow trout usurp a terrestrial prey subsidy from native charr and reduce their growth and abundance. *Oecologia* 153:461–70.

Blanchet, S., G. Loot, L. Bernatchez, and J.J. Dodson. 2007. The disruption of dominance hierarchies by a non-native species: An individual-based analysis. *Oecologia* 152:569–81.

Blinn, D.W., C. Runck, D.A. Clark, and J.N. Rinne. 1993.

Effects of rainbow trout predation on little Colorado spinedace. *Trans. Am. Fish. Soc.* 122:139–43.

Bowser, P.R. 2009. Fish diseases: Viral Hemorrhagic Septicemia (VHS). Northeastern Regional Aquaculture Center, University of Maryland. Publication No. 201–2009.

Bryan, S.D., A.T. Robinson, and M.G. Sweetser. 2002. Behavioral responses of a small native fish to multiple introduced predators. *Environ. Biol. Fish.* 63:49–56.

Cambray, J.A. 2003. The global impact of alien trout species—a review with reference to their impact in South Africa. *Afr. J. Aquat. Sci.* 28:61–67.

Carmichael, G.J., J.N. Hanson, M.E. Schmidt, and D.C. Morizot. 1993. Introgression among apache, cutthroat, and rainbow trout in Arizona. *Trans. Am. Fish. Soc.* 122:121–30.

Carpenter, J., and G.A. Mueller. 2008. Small non-native fishes as predators of larval razorback suckers. *Southwest. Nat.* 53:236–42.

CFSPH (Center for Food Security and Public Health). 2007. *Infectious Hematopoietic Necrosis*. Center for Food Security and Public Health, Institute for International Cooperation in Animal Biologics, Iowa State University, World Organization for Animal Health. http://www.cfsph.iastate.edu/Factsheets/pdfs/infectious_hematopoietic_necrosis.pdf.

Crawford, S.S. 2001. Salmonine introductions to the Laurentian Great Lakes: An historical review and evaluation of ecological effects. *Can. Spec. Publ. Fish. Aquat. Sci.,* 132.

Crowl, T.A., C.R. Townsend, and A.R. McIntosh. 1992. The impact of introduced brown and rainbow trout on native fish: The case of Australasia. *Rev. Fish Biol. Fish.* 2:217–41.

Cucherousset, J., J.C. Aymes, N. Poulet, F. Santoul, and R. Cereghino. 2008. Do native brown trout and non-native brook trout interact reproductively? *Naturwiss.* 95:647–54.

Cucherousset, J., and J.D. Olden. 2011. Ecological impacts of non-native freshwater fishes. *Fisheries* 36:215–30.

Deverill, J.I., C.E. Adams, and C.W. Bean. 1999. Prior residence, aggression and territory acquisition in hatchery-reared and wild brown trout. *J. Fish Biol.* 55:868–75.

Dewald, L., and M.A. Wilzbach. 1992. Interactions between native brook trout and hatchery brown trout: Effects on habitat use, feeding, and growth. *Trans. Am. Fish. Soc.* 121:287–96.

Dunham, J.B., D.S. Pilliod, and M.K. Young. 2004. Assessing the consequences of non-native trout in headwater ecosystems in western North America. *Fisheries* 29:18–26.

East, P., and P. Magnan. 1991. Some factors regulating piscivory of brook trout, *Salvelinus fontinalis*, in lakes of the Laurentian Shield. *Can. J. Fish. Aquat. Sci.* 48:1735–43.

Eby, L.A., W.J. Roach, L.B. Crowder, and J.A. Stanford. 2006. Effects of stocking-up freshwater food webs. *Trends Ecol. Evol.* 21:576–84.

Fausch, K.D. 1988. Tests of competition between native and introduced salmonids in streams: What have we learned? *Can. J. Fish. Aquat. Sci.* 45:2238–46.

Flecker, A.S., and C.R. Townsend. 1994. Community-wide consequences of trout introduction in New Zealand streams. *Ecol. Appl.* 4:798–807.

Freeman, M.C., and G.D. Grossman. 1992. A field test for competitive interactions among foraging stream fishes. *Copeia,* 1992:898–902.

Garman, G.C., and L.A. Nielsen. 1982. Piscivory by stocked brown trout and its impact on the nongame fish community of Bottom Creek, Virginia. *Can. J. Fish. Aquat. Sci.* 39:862–69.

Gido, K.B., and D.L. Propst. 1999. Habitat use and association of native and non-native fishes in the San Juan River, New Mexico and Utah. *Copeia,* 1999:321–32.

Glova, G.J., and M.S. Field-Dodgson. 1995. Behavioral interaction between Chinook salmon and brown trout juveniles in a simulated stream. *Trans. Am. Fish Soc.* 124:194–206.

Griffith, J.S., Jr. 1972. Comparative behavior and habitat utilization of brook trout (*Salvelinus fontinalis*) and cutthroat trout (*Salmo clarki*) in small streams in northern Idaho. *J. Fish. Res. Board Can.* 29:265–73.

Harwood, A.J., S.W. Griffiths, N.B. Metcalfe, and J.D. Armstrong. 2003. The relative influence of prior residency and dominance on the early feeding behaviour of juvenile Atlantic salmon. *Anim. Behav.* 65:1141–49.

Hasegawa, K., and K. Maekawa. 2006. The effects of introduced salmonids on two native stream-dwelling salmonids through interspecific competition. *J. Fish Biol.* 68:1123–32.

Hoffman, G.L., and G. Schubert. 1984. Some parasites of exotic fishes. In *Distribution, Biology, and Management of Exotic Fishes*, ed. W.R. Courtenay, Jr., and J.R. Stauffer Jr., 233–61. Johns Hopkins University Press, Baltimore.

Janetski, D.J., A.H. Moerke, D.T. Chaloner, and G.A. Lamberti. 2011. Spawning salmon increase brook trout movements in a Lake Michigan tributary. *Ecol. Freshw. Fish* 20:209–19.

Johnson, J.H., and E.Z. Johnson. 1982. Diel foraging in relation to available prey in an Adirondack mountain stream fish community. *Hydrobiologia* 96:97–104.

Johnson, J.H., and N.H. Ringler. 1979. Predation on Pacific salmon eggs by salmonids in a tributary of Lake Ontario. *J. Great Lake Res.* 5:177–81.

Kadye, W.T., and C.H.D. Magadza. 2008. Trout induces a shift from preferred habitat types for indigenous species: The example of the indigenous catfish, *Amphilius uranoscopus* (Pfeffer, 1889), on an African montane plateau. *Hydrobiologia* 614:329–37.

Knight, G.L., and K.B. Gido. 2005. Habitat use and susceptibility to predation of four prairie stream fishes: Implications for conservation of the endangered topeka shiner. *Copeia,* 2005:38–47.

Konishi, M., S. Nakano, and T. Iwata. 2001. Trophic cascading effects of predatory fish on leaf litter processing in a Japanese stream. *Ecol. Res.* 16:415–22.

Krueger, C.C., and B. May. 1991. Ecological and genetic effects of salmonid introductions in North America. *Can. J. Fish. Aquat. Sci.* 48 (Suppl. 1): 66–77.

Kruse, C.G., W.A. Hubert, and F.J. Rahel. 2000. Status of Yellowstone cutthroat trout in Wyoming waters. *N. Am. J. Fish. Manage.* 20:693–705.

L'Abée-Lund, J.H., A. Langeland, and H. Sægrov. 1992. Piscivory by brown trout *Salmo trutta* L. and Arctic charr *Salvelinus alpinus* L. in Norwegian lakes. *J. Fish Biol.* 41:91–101.

L'Abée-Lund, J.H., P. Aass, and H. Sægrov. 2002. Long-term variation in piscivory in a brown trout population: Effect of changes in available prey organisms. *Ecol. Freshw. Fish,* 11:260–69.

Land, E.D., and R.C. Lacy. 2000. Introgression level achieved through Florida panther genetic restoration. *Endangered Species Update* 17:100–105.

Leary, R.F., F.W. Allendorf, and K.L. Knudsen. 1983. Consistently high meristic counts in natural hybrids between brook trout and bull trout. *Syst. Zool.* 32:369–76.

Levin, P.S., S. Achord, B.E. Feist, and R.W. Zabel. 2002. Non-indigenous brook trout and the demise of Pacific salmon: A forgotten threat? *Proc. Biol. Sci.* 269:1663–70.

MacRae, P.S.D., and D.A. Jackson. 2001. The influence of smallmouth bass (*Micropterus dolomieu*) predation and habitat complexity on the structure of littoral zone fish assemblages. *Can. J. Fish. Aquat. Sci.* 58:342–51.

Marrin, D.L., and D.C. Erman. 1982. Evidence against competition between trout and nongame fishes in Stampede Reservoir, California. *N. Am. J. Fish. Manage.* 2:262–69.

Marsh, P.C., and M.E. Douglas. 1997. Predation by introduced fishes on endangered humpback chub and other native species in the Little Colorado River, Arizona. *Trans. Am. Fish. Soc.* 126:343–46.

McGrath, C.C., and W.M. Lewis, Jr. 2007. Competition and predation as mechanisms for displacement of greenback cutthroat trout by brook trout. *Trans. Am. Fish. Soc.* 136:1381–92.

McHugh, P., and P. Budy. 2006. Experimental effects of non-native brown trout on the individual- and population-level performance of native Bonneville Cutthroat Trout. *Trans. Am. Fish. Soc.* 135:1441–55.

McIntosh, A.R., T.A. Crowl, and C.R. Townsend. 1994. Size-related impacts of introduced brown trout on the distribution of native common river galaxias. *N.Z. J. Mar. Freshwater Res.* 28:135–44.

Miller, R.B. 1958. The role of competition in the mortality of hatchery trout. *J. Fish. Res. Board of Can.* 15:27–45.

Nannini, M.A., and M.C. Belk. 2006. Antipredator responses of two native stream fishes to an introduced predator: Does similarity in morphology predict similarity in behavioural response? *Ecol. Freshw. Fish* 15:453–63.

Nasmith, L.E., W.M. Tonn, C.A. Paszkowski, and G.J. Scrimgeour. 2010. Effects of stocked trout on native fish communities in boreal foothills lakes. *Ecol. Freshw. Fish* 19:279–89.

Olsen, D.G., and M.C. Belk. 2005. Relationship of diurnal habitat use of native stream fishes of the Eastern Great Basin to presence of introduced salmonids. *West. N. Am. Naturalist* 65:501–6.

Pardo, R., I. Vila, and J.J. Capella. 2009. Competitive interaction between introduced rainbow trout and native silverside in a Chilean stream. *Environ. Biol. Fish.* 86:353–59.

Penaluna, B.E., I. Arismendi, and D. Soto. 2009. Evidence of interactive segregation between introduced trout and native fishes in northern Patagonian Rivers, Chile. *Trans. Am. Fish. Soc.* 138:839–45.

Peterson, D.P., and K.D. Fausch. 2003. Testing population-level mechanisms of invasion by a mobile vertebrate: A simple conceptual framework for salmonids in streams. *Biol. Invasions* 5:239–59.

Peterson, D.P., K.D. Fausch, and G.C. White. 2004. Population ecology of an invasion: Effects of brook trout on native cutthroat trout. *Ecol. Appl.* 14:754–72.

Pritchard, V.L., and D.E. Cowley. 2006. Rio Grande cutthroat trout (*Oncorhynchus clarkia virginalis*): A technical conservation assessment. USDA Forest Service, Rocky Mountain Region. *http://www.fs.fed.us/r2/projects/scp/assessments/riograndecutthroattrout.pdf (accessed September 28, 2011).*

Rinne, J.N., and M. Alexander. 1995. Non-native salmonid predation on two threatened native species: Preliminary observations from field and laboratory studies. *Proc. Desert Fishes Counc. 1994 Symposium* 26:114–16.

Ruetz, C.R., III, A.L. Hurford, and B. Vondracek. 2003. Interspecific interactions between brown trout and slimy sculpin in stream enclosures. *Trans. Am. Fish. Soc.* 132:611–18.

Shafland, P.L. 1996. Exotic fish assessments: An alternative view. *Rev. Fish. Sci.* 4:123–32.

Simon, K.S., and C.R. Townsend. 2003. Impacts of freshwater invaders at different levels of ecological organisation, with emphasis on salmonids and ecosystem consequences. *Freshwater Biol.* 48:982–94.

Stuart-Smith, R.D., J.F. Stuart-Smith, R.W.G. White, and L.A. Barmuta. 2007. The impact of an introduced predator on a threatened galaxiid fish is reduced by the availability of complex habits. *Freshwater Biol.* 52:1555–63.

Taniguchi, Y., K.D. Fausch, and S. Nakano. 2002. Size-structured interactions between native and introduced species: Can intraguild predation facilitate invasion by stream salmonids? *Biol. Invasions* 4:223–33.

Taylor, J.N., W.R. Courtenay, Jr., and J.A. McCann. 1984. Known impacts of exotic fishes in the continental United States. In *Distribution, Biology, and Management of Exotic Fishes*, ed. W.R. Courtenay, Jr., and J.R. Stauffer, Jr., 322–73. Johns Hopkins University Press, Baltimore.

Townsend, C.R., and T.A. Crowl. 1991. Fragmented structure in a native New Zealand fish: An effect of introduced brown trout? *Oikos* 61:347–54.

USFWS (U.S. Fish and Wildlife Service). 2002a. Gila trout recovery plan (third revision). Albuquerque, NM. http://www.fws.gov/southwest/es/Arizona/Documents/RecoveryPlans/Gila_Trout_Recovery_Plan_(Draft_3rd_revised).pdf (accessed September 13, 2011).

USFWS (U.S. Fish and Wildlife Service). 2002b. Endangered and threatened wildlife and plants; 90-day finding on a petition to list the California golden trout as endangered. Federal Register 67 (183): 592241-43. http://ecos.fws.gov/docs/federal_register/fr3950.pdf (accessed September 13, 2011).

USFWS (U.S. Fish and Wildlife Service). 2004. Revised recovery plan for the Paiute cutthroat trout (*Oncorhynchus clarki seleniris*). Portland, OR.

Walsh, M.G., and D.L. Winkelman. 2004. Fish assemblage structure in an Oklahoma Ozark stream before and after rainbow trout introduction. *Am. Fish. Soc. Symp.* 44:417–30.

Weber, E.D., and K.D. Fausch. 2003. Interactions between hatchery and wild salmonids in streams: Differences in biology and evidence for competition. *Can. J. Fish. Aquat. Sci.* 60:1018–36.

Williams, J.E., J.E. Johnson, D.A. Hendrickson, S. Contreras-Balderas, J.D. Williams, M. Navarro-Mendoza, D.E. McAllister, and J.E. Deacon. 1989. Fishes of North America endangered, threatened, or of special concern: 1989. *Fisheries* 14:2–20.

Yard, M.D., L.G. Coggins Jr., C.V. Baxter, G.E. Bennett, and J. Korman. 2011. Trout piscivory in the Colorado River, Grand Canyon: Effects of turbidity, temperature, and fish prey availability. *Trans. Am. Fish. Soc.* 140:471–86.

Zimmerman, J.K.H., and B. Vondracek. 2007. Interactions between slimy sculpin and trout: Slimy sculpin growth and diet in relation to native and non-native trout. *Trans. Am. Fish. Soc.* 136:1791–1800.