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Pathways of unauthorized fish introductions and types of management responses

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Abstract Unauthorized introductions are an ongoing problem for fisheries managers. To understand reasons for the continued spread of nonnative fish species, the pathways of nonnative fish introductions were analyzed from 1961 to 2017 in Wyoming, USA. Unauthorized introductions are those that occurred without oversight of a management agency. The largest source of unauthorized introductions was the deliberate, illegal release of fish by the public at 46% of the 215 introduction events. The next largest source was colonization of new water bodies after initial establishment at 29%. Inadvertent (accidental) stockings (8%) and unknown sources (17%) were the other pathways documented. Management responses consisted of attempts at complete eradication (9%), population reduction (10%), or containment (3%) although in the majority of introductions (79%) no action was taken. The introductions involved 49 taxa but three sport fish constituted 26.5% of all events: brook trout *Salvelinus fontinalis*, walleye *Sander vitreus*, and yellow perch *Perca flavescens*. The prevalence of illegal introductions and the difficulty of eradicating introduced species indicate the continuing need for public education and enforcement efforts. The high frequency whereby species colonize new waterbodies indicates that fish introductions, even those authorized by management agencies, must consider the high probability that species will expand into unintended waterways.

Keywords Fish introduction · Invasive species · Invasion pathways · Illegal introduction · Unauthorized introductions

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Introduction

Fish introductions have a complex history in the United States. When the country was being settled, intentional introductions by fishery agencies were common as biologists sought to provide additional sources of sustenance and, later, to meet the increasing demands of harvest-oriented recreational anglers (Rahel, 2016). Even conservation organizations were

involved in fish introductions in the past. For example, in the late 1800s, members of the Sierra Club moved golden trout *Oncorhynchus aguabonita* (Jordan, 1892) across drainages in California to stock into fishless lakes (Rahel, 1997). In some cases, citizens were organized into acclimation societies that used private funds to establish nonnative species in new habitats. The Country Club of San Francisco had a mission to expand the distribution of European brown trout *Salmo trutta* (Linnaeus, 1758) throughout California in the 1800s (Lever, 2011). At the local scale, it was common and even considered admirable for citizens to take it upon themselves to introduce sport fishes into their favorite fishing spots. In 1879, a newspaper in Laramie, Wyoming wrote approvingly of the efforts of several individuals who secretly caught trout in Colorado and transported them back to Wyoming to stock in the Laramie River. The earliest introductions of two of the most prevalent trout species in Colorado, brook trout *Salvelinus fontinalis* (Mitchill, 1814) and brown trout, were the results of private stockings in the late nineteenth century (Wiltzius, 1985). And from 1879 to 1896, citizens could receive a rail shipment of common carp *Cyprinus carpio* (Linnaeus 1758) from the U.S. Fish Commission hatchery in Washington D.C. to stock wherever they wished (Cooper, 1987).

But as the fields of ecology and fisheries management developed, it became apparent that allowing unfettered fish introductions by the public was not a good idea. Initially the concern was that introductions could ruin successful fisheries by supplanting desirable sport fish species with undesirable "rough fish" species such as suckers (Catostomidae) released as unused bait (Spratt, 1946). Interestingly, in many cases, the desirable sport fish species had themselves been introduced at an earlier period or were the result of continual stocking efforts (Remmick, 1982). Later, as a conservation ethic became more prevalent in fisheries management, introductions were seen as harmful to indigenous species, including many non-game fishes (Rahel, 1997).

To reduce the dissemination of fish by the public, states began enacting regulations that prohibited the introduction of fish species without approval from the appropriate fisheries management agency. The first such regulation in Wyoming occurred in 1937 when the Wyoming Game and Fish Commission stated that "no person shall plant or release in any of the public waters of this State any fish, fingerling, fry or fish eggs except with the consent and under the direct supervision of the Wyoming Game and Fish Commission …" This ban was further enforced by a series of regulations starting in the 1950s that restricted where live bait fish could be used, which species could be used as bait, and prohibited the release of unused bait fish (Rahel, 2016). In 1937, the U.S. National Parks system adopted a policy prohibiting the introduction of nonnative fish species in national park or monument waters (Madsen, 1937). By the 1970s, nearly all states in the U.S. had laws restricting the importation, possession, and release of fish (Courtenay & Robins, 1975).

But regulations have not stopped the unauthorized stocking of fish. Despite widespread public education campaigns, bans on fish stocking without government approval, and increasingly hefty fines, new fish species continue to appear in waters where they were not part of an agency-sanctioned introduction (Johnson et al., 2009; Strecker et al., 2011; Lapointe et al., 2016). Our objectives in the current study were to develop a categorization scheme for unauthorized introductions and to explore the responses by management agencies to such introductions. We focus on data from Wyoming, U.S.A. but our results should reflect introduction pathways and management responses for other states and Canadian provinces in western North America.

Methods

Categorizing species introductions

We defined introduction to be the occurrence of a fish species, subspecies, or hybrid in a waterbody where it did not naturally occur prior to European settlement. Fish introductions can be divided into two broad categories: authorized or unauthorized. Authorized introductions are those done with the approval of a management or regulatory agency. Such introductions may be done by the agency itself or by members of the public after obtaining permission from the agency. These introductions are subject to a vetting process to evaluate the potential for negative ecological effects on the recipient waterbody. Even if the introduction is to occur on private land, the potential for the species to spread to other waterbodies is an important consideration in the evaluation process. Authorized

introductions are a major component of fisheries management in the United States and Canada where over a billion hatchery-reared fish of over 100 types are stocked annually to support recreational and commercial fisheries and to assist in the recovery of species of conservation concern (Trushenski et al., 2010; Lorenzen, 2014).

The other broad category, unauthorized introductions, involves illegal, inadvertent, or colonization pathways. These pathways share the property that they are not subject to a priori approval involving an ecological evaluation. This term is more inclusive than the often used term "illegal" because it encompasses a variety of mechanisms by which species may enter a waterbody without regulatory oversight (Table 1). These include illegal introductions where there is a deliberate release of fish that is in violation of legal statutes. Such illegal introductions include the release of sportfish, baitfish, or pet fish (Johnson et al., 2009). Unauthorized introductions can also include inadvertent introductions that are the result of contaminated fish stockings, human error in the stocking process, or a by-product of some other human activity such as ballast water release (Davies et al., 2013; Jacobs & Keller, 2017). In our study, contaminated fish stockings were usually detected when biologists spotted unwanted fish species entering the waterbody during the stocking process, or after-the-fact by tracing the chemical signatures of otoliths back to the water source where the suspected stocked fish had been raised. Unauthorized stockings can also involve situations where fish colonize additional waterbodies throughout a drainage network without direct human assistance (Gardunio et al., 2011) or as a by-product of improved connectivity among systems (e.g., Rahel, 2013; Kornis et al., 2015). In some cases, these are fish that are the result of an authorized stocking and later emigrate to other waterbodies where their presence is undesirable. In other cases, fish that are the result of an unauthorized stocking in one location may colonize new locations without direct human assistance.

Categorizing management responses to unauthorized fish introductions

After an unauthorized introduction event has occurred, management responses fall into four categories: eradication, population reduction, containment, or no action (Table 2). Complete eradication is the most ecologically desirable response because it provides a permanent solution to the problem. Eradication can be accomplished by the use of piscicides that have minimal long-term effects on other aquatic organisms (but see Vinson et al., 2010) or by draining the waterbody. Both methods are intended to kill all fish present, and hence pre-treatment salvage efforts are needed to prevent the loss of desirable fish, especially taxa of conservation concern. Repeated removal by

Table 1 Categories of unauthorized fish species introductions

Category	Characteristics of such introductions
Illegal	Perpetrators knowingly introduce a species into a waterbody
Sportfish	Game species are introduced, usually to establish a new fishery
Baitfish	Live bait fish are released, usually at the end of the fishing day
Pet fish	Pet fish from aquaria or water gardens are released
Inadvertent	Perpetrators are not aware they are introducing a fish species into an unintended water body. Often referred to as accidental introductions
Contaminant	Unwanted species present in source of intentionally stocked fish
Stocking error	Human error results in stocking of fish into unintended waterbody
By-product	Species are unintentionally introduced as a by-product of human activities such as ballast water releases
Colonization	Nonnative species spread without direct human assistance to new habitats where their presence was not intended
Authorized source	Fish from an authorized stocking event colonize new locations
Unauthorized source	Fish from an unauthorized stocking event or unknown source colonize new locations
Unknown	Not enough information is available to assign the introduction event to one of the above categories

Table 2 Categories of management responses to unauthorized fish introductions in Wyoming

Categories	Description of the management action
Complete eradication (9%)	Attempt to remove entire population of unwanted fish from waterbody
Piscicide (8%)	Use of chemicals that are lethal to fish.
Dewatering (1%)	Remove water from waterbody to kill all fish, and then refill waterbody
Population reduction (10%)	When total eradication is not possible, seek to reduce the population size
Physical removal (5%)	Use of nets, weirs, or electrofishing to reduce the population
Angler harvest (7%)	No creel limit and/or mandatory kill of undesired fish caught by anglers
Biological control (1%)	A predator species is stocked to control introduced species. Predators are typically sterile hybrids such as tiger muskellunge or tiger trout
Containment (3%)	Construct fish movement barriers or cease authorized stockings to prevent from colonizing habitats where they are not wanted
No action (79%)	No management actions are undertaken. This may occur when control methods are logistically, economically, or sociologically unfeasible, or when the effects of the unauthorized species are considered to be minor

Numbers in parentheses refer to the percentage of 215 unauthorized introductions surveyed in the present study that fall into each category or subcategory. Multiple management actions were used for some waterbodies

nets or electrofishing may eventually eliminate an unwanted fish species but this involves tremendous effort and is only feasible for small, isolated habitats where recolonization is not possible (Shepard et al., 2002; Knapp et al., 2007). Often complete eradication is not possible due to the large size of the waterbody, the complexity of a drainage network, continued recolonization from adjacent sources, or opposition by the public. In such cases, reducing the population of the undesirable fish species is the next best management option. This can be undertaken through physical means such as netting, electrofishing, or operating fish weirs where the idea is to target the unwanted species while minimizing harm to other species. For example, extensive netting of lake trout *Salvelinus namaycush* (Walbaum, 1792) in Yellowstone Lake is focused on areas where this illegally introduced species is relatively segregated from Yellowstone cutthroat *Oncorhynchus clarkii bouvieri* (Jordan & Gilbert, 1883), a species of conservation concern (Syslo et al., 2011). Weirs associated with fishways can be used to selectively remove undesirable species while allowing upstream passage of desirable species (Pratt et al., 2009). Repeated electrofishing can also be used to suppress fish populations if eradication is not feasible (Peterson et al., 2008). But these methods must be applied repeatedly because populations of the unwanted fish species generally recover quickly when removal efforts cease. Recently, there has been interest in enlisting the help of anglers to control undesirable fish taxa by removing harvest limits, offering bounties, or by requiring that all individuals of the targeted taxa be killed, even if they are not to be used for human consumption (Pasko & Goldberg, 2014; Klein et al., 2016). Containment refers to efforts to prevent the spread of the species by employing barriers to movement such as dams, acoustic barriers, or electrical fields (Rahel, 2013).

Data sources for unauthorized fish introductions and management responses

To evaluate the relative importance of the different pathways for unauthorized fish introductions, we examined unauthorized fish introductions that occurred in Wyoming during 1961–2017. Most of these introduction events were documented by Wyoming Game and Fish Department fisheries biologists or by university researchers. Major sources of data were annual fisheries progress reports published by the Wyoming Game and Fish Department, personal communications with regional fish biologists, peer-reviewed journal articles, and graduate student theses or dissertations at the University of Wyoming (see

Electronic Supplementary Material). For each introduction, we relied on the determination made in the original data source as to which introduction pathway was most likely except when current fishery managers provided updated information. Whether the introduced species had become established was evaluated from information provided in the original data source and by consulting current regional fisheries managers. Criteria used to determine if a species was established included the capture of multiple individuals from several size classes and the occurrence of the species across multiple years. Information on the management response to the unauthorized introduction came from annual fisheries progress reports and from communications with regional biologists. Two of the taxa were sterile hybrids (splake *Salvelinus fontinalis* × *S. namaycush* and tiger muskellunge *Esox lucius* × *E. masquinongy*) but these were considered as separate taxa for data analysis. However, these two hybrids were never considered to have become established because their persistence depended upon continual stocking. After the dataset was assembled, it was reviewed by regional fisheries biologists of the Wyoming Game and Fish Department for accuracy regarding species introductions and management responses.

Results

We found records for 215 unauthorized introduction events in Wyoming during 1961–2017 (Table 3). These introductions involved a wide variety of fish taxa including 47 species and 2 hybrid taxa (tiger muskellunge and splake). The vast majority of the introductions involved species that were either native somewhere in the state (n = 18) or were nonnatives (n = 21) that were already naturalized somewhere in the state but which were recorded in a new location. As for the other eight species, one was not native to the state and does not appear to have established a population (yellow bullhead, *Ameiurus natalis* (Lesueur, 1819)); one likely colonized from another state and has an established population (western mosquitofish, *Gambusia affinis* (Baird & Girard, 1853)); four were aquarium species that had become established in a single warm spring (convict cichlid, *Amatitlania nigrofasciata* (Günther, 1867); green swordtail *Xiphophorus hellerii* (Heckel, 1848); guppy *Poecilia reticulate* (Peters, 1859); tadpole madtom *Noturus gyrinus* (Mitchill, 1817)); and two were aquarium species that did not establish populations (Amazon sailfin catfish *Pterygoplichthys pardalis* (Castelnau, 1855) and Pacu (family Serrasalmidae)). Although many types of fish have been introduced via unauthorized pathways, a few species are responsible for the majority of introductions. Three nonnative sportfish species collectively accounted for about a quarter (26.5%) of all unauthorized introduction events: brook trout, walleye *Sander vitreus* (Mitchill, 1818), and yellow perch *Perca flavescens* (Mitchill, 1814) (Fig. 1). The vast majority of introduced taxa were either sport fish or bait fish. Introduction events involving pet fish were rare and involved goldfish *Carassius auratus* (Linnaeus, 1758) with nine introductions and the previously mentioned aquarium species with a single introduction each.

Illegal introductions as defined in Table 1 were the most prevalent type of unauthorized introduction (Fig. 2). Collectively they constituted 46% of the 215 events and consisted of introductions involving sport fishes (26%), bait fishes (12%), and pet fishes (7%). The next most prevalent type of unauthorized introductions involved fish colonizing new waterbodies (29%). These included fish that originated from an authorized stocking in a nearby waterbody (15%) or fish that originated from an unauthorized stocking or unknown source (14%). Inadvertent introductions were uncommon (8%) and consisted of events where the source of fish for an authorized stocking was contaminated with other fish species (5%) or where human error led to fish being stocked in the wrong waterbody (3%). The introduction pathway for 17% of the introduction events was unknown. Of the 215 detected introduction events, 63% resulted in establishment of the fish species. This percentage increases slightly to 64% if the four events involving introductions of sterile splake or tiger muskellunge are removed from the total.

The vast majority of introduction events (79%) resulted in no actions to eliminate, reduce, or contain the population of the introduced fish (Table 2). In only a small proportion of cases were there efforts at complete eradication (9%) and these consisted of the use of piscicides (8%) or pond dewatering (1%) to kill all of the undesired fish. Efforts at population reduction occurred for 10% of the introduction events and these consisted of physical removal by electrofishing

Table 3 Summary of 215 unauthorized fish introductions in Wyoming (1961–2017). Shown are the number of introductions for each taxon, number of events (No.) partitioned according to pathway, the number that resulted in established populations, and the management actions undertaken. Unk. refers to unknown pathway

Taxa	No.	Introduction pathway				Established populations	Management action			
		Illegal	Inadvertent	Colonize	Unk.		Eradicate	Reduce	Contain	None
Cyprinidae										
Common carp *Cyprinus carpio* (Linnaeus 1758)	1	0	0	0	1	1	0	0	0	1
Fathead minnow *Pimephales promelas** (Rafinesque, 1820)	9	7	0	1	1	8	0	0	0	9
Finescale dace *Chrosomus neogaeus** (Cope, 1867)	1	0	1	0	0	0	0	0	0	1
Golden shiner *Notemigonus crysoleucas* (Mitchill, 1814)	2	2	0	0	0	1	0	0	0	2
Goldfish *Carassius auratus* (Linnaeus, 1758)	10	10	0	0	0	4	1	0	0	9
Lake chub *Couesius plumbeus** (Agassiz, 1850)	4	4	0	0	0	2	0	0	0	4
Plains minnow *Hybognathus placitus** (Girard, 1856)	1	1	0	0	0	1	0	0	0	1
Red shiner *Cyprinella lutrensis** (Baird & Girard, 1853)	1	0	0	1	0	1	0	0	0	2
Redside shiner *Richardsonius balteatus** (Richardson, 1836)	3	1	0	1	1	3	0	0	0	3
Sand shiner *Notropis stramineus** (Cope, 1865)	1	0	0	1	0	1	0	0	0	1
Speckled dace *Rhinichthys osculus** (Girard, 1856)	1	1	0	0	0	1	0	0	0	1
Utah chub *Gila atraria** (Girard, 1856)	2	2	0	0	0	2	0	1	0	0
Catostomidae										
White sucker *Catostomus commersonii** (Lacépède 1803)	10	2	0	2	6	8	2	1	0	7
Utah sucker *Catostomus ardens** (Jordan & Gilbert, 1881)	1	0	0	0	1	1	0	0	0	1
Fundulidae										
Plains killifish *Fundulus kansae** (Jordan & Gilbert, 1883)	1	0	0	0	1	0	0	0	0	1
Poeciliidae										
Western mosquitofish *Gambusia affinis* (Baird & Girard, 1853)	1	0	0	0	1	1	0	0	0	1
Ictaluridae										
Black bullhead *Ameiurus melas** (Rafinesque, 1820)	5	3	0	2	0	3	1	0	0	4

Table 3 continued

Taxa	No.	Introduction pathway				Established populations	Management action			
		Illegal	Inadvertent	Colonize	Unk.		Eradicate	Reduce	Contain	None
Channel catfish *Ictalurus punctatus** (Rafinesque, 1818)	1	1	0	0	0	0	0	0	0	1
Yellow bullhead *Ameiurus natalis* (Lesueur, 1819)	1	0	0	1	0	0	0	0	0	1
Esocidae										
Northern pike *Esox lucius* (Linnaeus, 1758)	8	3	2	2	1	1	1	4	1	2
Tiger muskellunge *E. lucius* × *E. masquinongy*	1	0	0	1	0	0	0	1	0	0
Salmonidae										
Brook trout *Salvelinus fontinalis* (Mitchill, 1814)	21	3	1	12	5	17	5	1	2	15
Brown trout *Salmo trutta* (Linnaeus, 1758)	10	3	1	5	1	4	0	0	1	9
Cutthroat trout *Oncorhynchus clarkii** (Richardson, 1836)	8	2	2	3	1	3	0	1	0	7
Golden trout *Oncorhynchus aguabonita* (Jordan, 1893)	4	1	0	3	0	4	0	0	0	4
Grayling *Thymallus arcticus** (Pallas, 1776)	3	1	0	2	0	0	0	0	0	3
Kokanee *Oncorhynchus nerka* (Walbaum, 1792)	1	0	1	0	0	0	0	0	0	1
Lake trout *Salvelinus namaycush* (Walbaum, 1792)	4	1	1	2	0	3	0	1	0	3
Rainbow trout *Oncorhynchus mykiss* ((Walbaum, 1792)	5	1	0	4	0	3	1	1	2	1
Splake *S. fontinalis* × *S. namaycush*	3	0	2	1	0	0	0	0	0	3
Gadidae										
Burbot *Lota lota** (Linnaeus, 1758)	6	2	0	4	0	6	0	6	0	0
Gasterosteidae										
Brook stickleback *Culaea inconstans* (Kirtland, 1840)	16	5	2	6	3	14	4	0	0	12
Centrarchidae										
Black crappie *Pomoxis nigromaculatus* (Lesueur, 1829)	3	1	0	0	2	1	0	0	0	3
Bluegill *Lepomis macrochirus* (Rafinesque, 1819)	3	1	0	0	2	2	0	0	0	3
Green sunfish *Lepomis cyanellus* (Rafinesque, 1819)	7	5	1	0	1	5	1	0	0	6
Largemouth bass *Micropterus salmoides* (Lacépède, 1802)	6	2	0	3	1	3	0	0	0	6

Table 3 continued

Taxa	No.	Introduction pathway				Established populations	Management action			
		Illegal	Inadvertent	Colonize	Unk.		Eradicate	Reduce	Contain	None
Pumpkinseed *Lepomis gibbosus* (Linnaeus, 1758)	1	0	0	0	1	0	0	0	0	1
Smallmouth bass *Micropterus dolomieu* (Lacépède, 1802)	2	2	0	0	0	2	0	0	0	2
White crappie *Pomoxis annularis* (Rafinesque, 1818)	1	1	0	0	0	0	0	0	0	1
Percidae										
Iowa darter *Etheostoma exile** (Girard, 1859)	1	1	0	0	0	1	0	0	0	1
Walleye *Sander vitreus* (Mitchill, 1818)	18	11	1	5	1	7	1	3	0	14
Yellow perch *Perca flavescens* (Mitchill, 1814)	18	12	0	1	5	13	2	1	0	15
Sciaenidae										
Freshwater drum *Aplodinotus grunniens* (Rafinesque, 1819)	3	0	2	1	0	2	0	0	0	3
Tropical species[a]	6	6	0	0	0	4	0	0	0	6
Total for each category	215	98	17	64	36	136	20	20	5	172

[a]Six tropical species were each represented by one introduction event each: Convict cichlid *Amatitlania nigrofasciata* (Günther, 1867); guppy *Poecilia reticulate* (Peters, 1859); green swordtail *Xiphophorus hellerii* (Heckel, 1848); tadpole madtom *Noturus gyrinus* (Mitchill, 1817); Amazon sailfin catfish *Pterygoplichthys pardalis* (Castelnau, 1855); Pacu (family Serrasalmidae). The first four of these have established populations in Kelly Warm Springs, Teton County

* Species native to Wyoming

or netting (5%), promoting angler harvest by removing creel limits or requiring mandatory kill of the undesired fish (7%), or biological control through stocking of a predator (1%). These sum to more than 10% because in five instances, more than one type of population reduction effort occurred. Attempts at containing the undesired fish were uncommon (3%) and generally involved building migration barriers on streams to prevent fish from spreading upstream.

Discussion

Illegal stocking of sport fishes and bait fishes by the public are common pathways for unauthorized introductions in Wyoming and throughout western North America. Three nonnative sportfish species collectively accounted for about a quarter of all unauthorized introduction events in Wyoming: brook trout, walleye, and yellow perch. The prevalence of sportfish stockings reflects the fact that western drainages were depauperate of popular game fishes familiar to settlers from the eastern United States (Rahel, 2000). Furthermore, the creation of extensive networks of reservoirs to store water in this arid region created much new habitat, especially for cool- and warmwater lacustrine species. Consequently, management agencies stocked many nonnative sport and prey fishes to create recreational fisheries. Even today, nonnative species such as rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792), brook trout, brown trout, and walleye are routinely stocked to maintain or enhance fishing opportunities throughout the western United States. But stocking by management agencies is generally done after considering the fishery and ecological implications of fish introductions. Unfortunately, illegal stockings do not undergo such evaluations and there have been many negative effects of

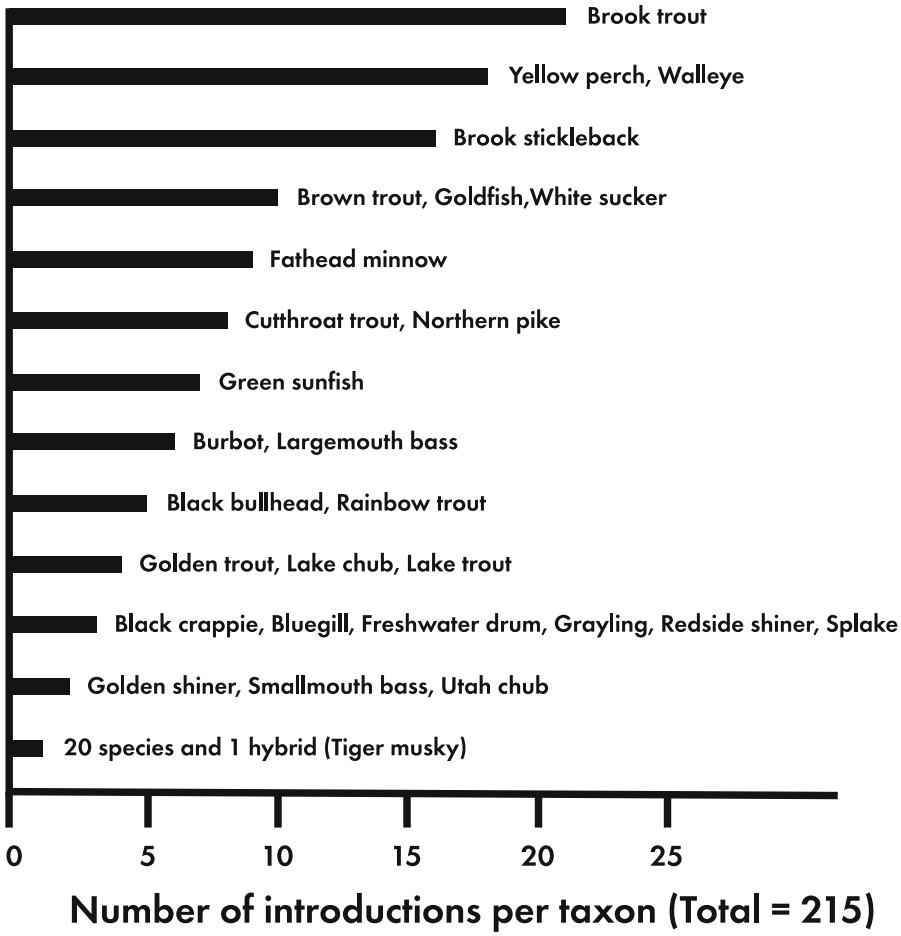

Fig. 1 Unauthorized introductions for 47 fish species and 2 hybrids in Wyoming during 1961–2017. Numbers refer to the number of introduction events across all types of introduction categories. Six tropical species each had one introduction event: convict cichlid, green swordtail, guppy, tadpole madtom, Amazon sailfin catfish, and Pacu

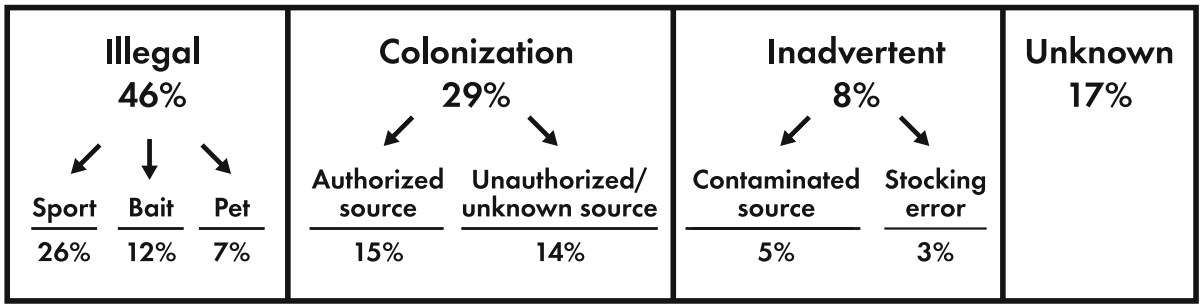

Fig. 2 The percentage of 215 unauthorized fish introduction events in Wyoming partitioned into four major pathway categories: illegal, colonizations, inadvertent, or unknown. Illegal introductions are further partitioned into those involving sport fish, bait fish, or pet (aquarium) fish. Introductions associated with colonization are partitioned into those where fish emigrated from a previously authorized introduction versus those where fish emigrated from either an unauthorized introduction or an unknown source. Inadvertent introductions are partitioned into those due to a contaminated stocking source versus those due to human error in the stocking process

unauthorized fish introductions on aquatic ecosystems (McMahon & Bennett, 1996; Koel et al., 2005; Carey et al., 2011; Drake et al., 2015).

Johnson et al. (2009) identified two types of people who engage in illegal introductions and suggested that deterring them will require different strategies. They

considered one type, "depreciative actors," to be people who are uninformed about the law and the detrimental effects of unauthorized stocking. In fact, they may even believe that their stocking activities are beneficial, such as releasing unused baitfish to provide a forage subsidy for game fish (Drake et al., 2015). Education is considered the best way to change the behavior of people in this group. The hope is that they will respond to well-supported arguments about the negative effects of illegal stocking on recreational fisheries, ecosystems, and local economies. The second type, "vandalistic actors," stock fish illegally despite awareness of the law and potential negative effects. The strategies to deter such people involve steep fines, witness rewards, highly visible enforcement, and revocation of fishing privileges. In Wyoming, there have been long-standing efforts to educate the public about stocking regulations and the harmful effects of unauthorized fish introductions (Remmick, 1982; Rahel, 2004; Wyoming Game and Fish Department, 2018). To provide a greater deterrent to people who introduce species illegally, the Wyoming state legislature increased the maximum fine for illegal stocking from $1,000 to $10,000 in 2010 (Rahel, 2016).

Although illegal introductions receive much attention, they constituted only about one-half of the reported unauthorized introductions in Wyoming. Colonization of new waterbodies following an initial establishment was another major pathway for unauthorized introductions. Movements of fish through interconnected waterways should be expected and movement of fish out of reservoirs is common (Wolff et al., 2012). However, extraordinary climatic events can allow fish to colonize waters not usually connected (Diez et al., 2012). For example, floods allowed black carp *Mylopharyngodon piceus* (Richardson, 1846) to escape from aquaculture ponds and enter the Missouri River in the southeastern United States (Nico et al., 2005). In Wyoming, the spread of walleye throughout the North Platte River system was facilitated by high spring runoff events that forced the spillage of water over dams (Mavrakis & Yule, 1998). Even where natural or anthropogenic barriers prevent the spread of a species, the purposeful establishment of a species creates a beachhead for human-assisted translocations to nearby waters. Such appears to be the case in Yellowstone Lake where illegally introduced lake trout were linked to a source population established by fisheries managers in a nearby lake a century earlier (Munro et al., 2005). In Wyoming, burbot *Lota lota* (Linnaeus, 1758) are native and managed as a highly valued sport fish east of the continental divide in the Wind River Mountains. But the species was moved, presumably by anglers, across the divide into the upper Colorado River basin in the early 1990s. There it is considered an invasive species and has spread throughout the basin through a combination of colonization and additional human-assisted introductions (Gardunio et al., 2011).

To prevent the spread of species within a drainage basin, barriers to fish movement can be constructed to intentionally fragment aquatic systems (Rahel, 2013). For example, a low head irrigation dam on the Little Snake River near Baggs, Wyoming was modified to prevent upstream incursions by nonnative northern pike *Esox lucius* (Linnaeus, 1758). The northern pike are established in downstream reaches but have been moving upstream where they threaten native fishes of conservation concern. Although barriers can be effective, they are costly, require constant maintenance, and can be breached by people intentionally moving fish past them (Harig et al., 2000). As noted above, the spread of species can occur when unusual climatic effects create connections among normally isolated aquatic systems. Awareness of such events can help guide stocking efforts so that future colonization events are minimized. For example, stocking nonnative game fish such as largemouth bass *Micropterus salmoides* (Lacépède, 1802) within portions of the Colorado River basin is only allowed if the waters to be stocked are above the 100-year floodplain and have no direct connection to the floodplain or, for lower elevations, if waters are bermed to the height of the 100-year floodplain and the outlet is screened prior to stocking (U.S. Fish and Wildlife Service, 2009). But even these guidelines will not prevent introductions during the extreme flood events that are predicted to occur more frequently with climate change. It should also be noted that the increasing efforts to remove dams and promote aquatic connectivity can have the unintended consequence of allowing the expansion of invasive aquatic organisms (Rahel, 2013; Kornis et al., 2015).

In our data set, inadvertent introductions were relatively uncommon, constituting only 8% of the introduction events. This is similar to the 8% of global fish introductions considered to be inadvertent, also

referred to as accidental (Gozlan et al., 2010). Globally, inadvertent introductions occurred mainly through escape from aquaculture installations or release of ship ballast water. Neither of these pathways were observed in Wyoming. Instead, inadvertent introductions involved either contaminants in authorized fish stockings or human error in the stocking location. For example, otolith isotopic signatures suggest the occurrence of northern pike in Grayrocks Reservoir in 2014 and Ocean Lake in 2015 were the result of this species being present in shipments of walleye that were intentionally stocked by the Wyoming Game and Fish Department (Wyoming Game and Fish Department, 2016). It is believed that a few northern pike were present in the ponds where walleye were being raised and were included when the walleye were collected for stocking. In a similar vein, freshwater drum *Aplodinotus grunniens* (Rafinesque, 1819) were introduced into Keyhole Reservoir and Grayrocks Reservoir as contaminants in authorized stockings of channel catfish (Baxter & Stone, 1995). To prevent such inadvertent introductions in the future, the Wyoming Game and Fish Department now systematically examines each shipment of warmwater fish obtained from outside the state by running fish across a shallow sorting board prior to stocking.

The other way for fish to be introduced inadvertently was through mix-ups during the stocking process. For example, a miscommunication between fisheries managers and hatchery workers resulted in brown trout being mistakenly stocked into Bear Lake in the Snowy Range Mountains of Wyoming in 1990 (Wyoming Game and Fish, 1990). The brown trout did not reproduce and eventually died out. In another case, difficulty in identifying remote lakes during aerial stocking resulted in cutthroat trout *Oncorhynchus clarkii* (Richardson, 1836) being placed into the wrong lake in the Cloud Peak Wilderness area in the Bighorn Mountains (Bradshaw, 2006). Recent sampling indicates the cutthroat trout did not become established. The challenge of locating remote lakes in wilderness is not unique to Wyoming. As Pister (2001) noted for aerial fish stocking in California "because it was difficult to accurately identify lakes when flying 100 meters above the ground at speeds approaching 200 knots, the wrong lakes were occasionally planted." Today, the use of global positioning systems to locate remote lakes and streams should reduce stockings into the wrong waterbody.

Management actions were undertaken in only 21% of the 215 introductions, although this increased to 32% of the 136 introductions where a species was thought to have become established. A lack of management response is generally because of uncertainty as to whether an undesired species will become established or will cause ecological harm. Thus, further monitoring is often the course of action. When it becomes evident that the undesired species is likely to become established, managers must decide whether to attempt complete eradication or to merely reduce the population size to minimize the impact of the offending species. Complete eradication is generally done with piscicides (Meronek et al., 1996). Because of the cost and permitting requirements involved in applying piscicides, their use is mainly restricted to situations where the introduced species is considered to have strong negative effects on other taxa, be likely to spread to other water bodies, and where the feasibility of eradication is high. Of the 215 introduction events in our data, only 8% (n = 18) resulted in piscicide use, although this increases to 13% of the 136 introductions where the species had become established. The most common situation where piscicides were used in Wyoming was to eliminate nonnative trout species in an effort to restore populations of native cutthroat trout. The success rate for complete eradication is often low in large, complex systems, and multiple treatments are usually needed to insure a complete kill. Eradication through physical removal by electrofishing or netting is possible in small systems with little habitat complexity and where chemical treatment is not feasible because of ecological, logistic, or political concerns (Shepard et al., 2002; Knapp et al., 2007). Situations where fish exist at a low population density and have a large size at maturity are most susceptible to this method (Gray et al., 2014). Another approach to eradication involves stocking a sterile piscivore to eliminate an undesired prey species. Koenig et al. (2015) found that tiger musky were able to eradicate nonnative brook trout in some Idaho alpine lakes without inlets or outlets. Because tiger musky are typically sterile, they would not become invasive themselves, as would be the case with one of their parental species, northern pike (McMahon & Bennett, 1996).

When eradication of an undesired fish species is not possible, population reduction may be the next best option. In the Wyoming data, efforts at population reduction occurred in 10% of the 215 introduction events, although such efforts increased to 19% of the 136 events where the introduced species became established. Removal through physical means such as electrofishing or netting is extremely labor intensive and must be done on a regular basis because most fish populations will quickly recover from such exploitation. Peterson et al. (2008) recommended that electrofishing removal to suppress nonnative brook trout and benefit native cutthroat should be done for three consecutive years, and then should not be interrupted for more than two consecutive years once initiated. Five years of gill netting in an isolated backcountry lake suppressed an invasive population of lake trout and benefited bull trout *Salvelinus confluentus* (Suckley, 1859), but this effort would need to be continued to ensure the lake trout population did not recover (Fredenberg et al., 2017). Physical removal efforts can be thwarted if immigration from source populations is not controlled (Zelasko et al., 2016). In Wyoming, unauthorized introductions led to sustained physical suppression efforts in only two cases. In the first case, fisheries biologists have been gill netting invasive lake trout in Yellowstone Lake since 1995 in an effort to reduce predation on native Yellowstone cutthroat trout, a species of conservation concern (Syslo et al., 2011). In the second case, removal of invasive walleye from Buffalo Bill Reservoir is being explored in an effort to reduce their predatory impact on native Yellowstone cutthroat trout. Walleye are removed by large mesh gillnets (nearly eliminating bycatch) when they are concentrated in a limited spawning area in the spring. Continuation of this program will depend on studies underway to determine its efficacy in reducing the walleye population.

Recently, there has been interest in enlisting the help of anglers to control undesirable fish taxa. Typically this is done by removing harvest limits, offering bounties, or by requiring that all individuals of the targeted taxa be killed, even if they are not to be used for human consumption (Pasko & Goldberg, 2014; Klein et al., 2016). There have also been efforts to promote human consumption of invasive species (Nuñez et al., 2012) and to stage fishing derbies to increase removal of unwanted fish and enhance public awareness of invasive species (Klein et al., 2016). Exploitation by anglers has been successful in reducing predation by northern pikeminnow *Ptychocheilus oregonensis* (Richardson, 1836) on salmon smolts in the Columbia River system. Anglers are paid $4–8 for each northern pikeminnow captured and are estimated to harvest about 12% of the adult population per year which reduces predation on juvenile salmonids by about 30% (Williams et al., 2016). A potential drawback of bounties is that they might become an incentive for further introductions. In many cases, exploitation by anglers is not high enough to effect a major reduction in the population of an undesired fish species (Pasko & Goldberg, 2014). For example, anglers were required to harvest all nonnative brook trout, while no harvest was allowed for native cutthroat trout and bull trout in a stream in the Canadian Rocky Mountains (Paul et al., 2003). After 3 years of intensive angler harvest, the brook trout population had not declined and the native trout populations had not increased. Brook trout were considered to be highly resilient to reductions by angling because of their ability to mature at small sizes and early ages when exploited. Even though recreational anglers catch approximately 20,000 lake trout per year in Yellowstone Lake and are required to kill all of them, this is only 5% of the total lake trout that are removed through the gill netting control program (https://www.nps.gov/yell/learn/nature/lake-trout.htm).

Even if fishing exploitation is not high enough to suppress the populations of the illegally introduced fish species, there are sociological reasons to employ unlimited harvest or mandatory kill regulations. Such a response sends a message to the angling public that illegal introductions will not be rewarded by creating a desirable fishery for those species. In line with this philosophy, the Wyoming Game and Fish Department has enacted mandatory kill regulations for yellow perch, walleye, northern pike, and burbot in all waters within the Colorado River drainage and for walleye in Buffalo Bill Reservoir (Wyoming Game and Fish Department, 2018). Similar mandatory kill regulations for invasive species are in effect for burbot, northern pike, smallmouth bass *Micropterus dolomieu* (Lacépède, 1802), walleye in the Green River of Utah (Utah Division of Wildlife Resources, 2018) and walleye in the Swan Lake drainage of Montana (Montana Fish, Wildlife & Parks, 2018a).

Our dataset has several limitations. Most introduced species do not become established, and hence

our estimate of establishment success is likely high. This overestimate of establishment success is because the waterbodies in our sample were not monitored continuously, and therefore biologists would be more likely to detect species that had become established versus species whose presence was ephemeral. Second, some of the pathway assignments could be wrong because how a species was introduced cannot always be determined with certainty. Where the source of nonnative fish was not obvious, such as contaminated stocking events, we relied on the judgement of local managers regarding introduction pathways. Third, the frequency of colonizations linked to authorized introductions may be underestimated in our dataset because such colonization events are often anticipated by fisheries managers and factored into assessment of the ecological risk associated with stocking. If stray individuals appear outside of the water body where they were stocked, they are considered to pose little ecological threat, and are less likely to be reported as an unauthorized colonization. By contrast, most unauthorized introductions are unanticipated and more likely to be reported by fisheries managers. Fourth, the management response to introduction may give a false impression of inaction. The high percentage of introductions where no management action was taken is not representative of how managers react to introductions that are problematic. Many introductions pose no threat to the fish assemblage and thus do not warrant expensive and time-consuming management actions (Johnson et al., 2009). If it is evident that the undesired species is likely to become established and cause ecological or economic harm, then managers are much more likely to undertake management actions. Despite these caveats, our data make clear that illegal introductions and the spread of species from initial introduction sites represent common pathways for the introduction of nonnative fishes in Wyoming and may be important in other places.

The relative importance of introduction pathways varies considerably among regions. In the Rocky Mountain region, the illegal introduction of sport fishes and their subsequent colonization of new habitats are the most important pathways (Johnson et al., 2009; Carey et al., 2011; Gardunio et al., 2011; current study). The frequency of illegal sport fish introductions reflects the lack of native game fish species, especially for reservoir habitats, and a fishing public that has come to expect nearby fisheries for their favorite species. Release of aquarium fish is the most important pathway in Great Britain (Keller et al., 2009) and Florida (Shafland et al., 2008), but is of minor importance in the Rocky Mountain region because cold winters prevent establishment of tropical fishes. Ballast water release is the major pathway in states and provinces in the Great Lakes region of North America (Kerr et al., 2005; Jacobs & Keller, 2017) but the Rocky Mountain region lacks a transoceanic shipping industry. In the Mid-Atlantic region of the United States, release of bait fish is a major pathway for fish introductions because propagule pressure is moderately high, most released species are adapted to local environmental conditions, and the pool of species available for transplantation is large (Lapointe et al., 2016). In many tropical regions, escape of fish from aquaculture facilities and subsequent colonization of new habitats is a major pathway for unauthorized introductions (Correa & Gross, 2008; Gozlan et al., 2010; Ortega et al., 2015). Escape from aquaculture is not a major source of fish introductions in the Rocky Mountain region currently, but one of the most widespread and invasive species in the region, common carp, originated from aquaculture sources in the late 1800s (Rahel, 1997).

The large number of unauthorized introductions that originated from colonization events is of concern. This means that even if introductions are properly vetted and thought to be ecologically benign for the waterbody in question, problems can arise when the species is able to colonize new water bodies. For example, Asian carp were originally imported into the United States to provide benefits in aquaculture ponds. But they subsequently escaped during flood events and spread throughout the Mississippi River system, causing ecological harm and affecting recreational activities (Chapman & Hoff, 2011). One of the anticipated effects of climate change is a greater frequency of extreme weather events which will increase the likelihood that species will be able to breach barriers that currently restrict their ability to colonize new habitats (Diez et al., 2012). The creation of source populations for future colonization should be an important consideration when assessing the consequences of species introductions.

The potential for unintended spread to new waterbodies is an important consideration in evaluating proposed introductions by management agencies.

Awareness of this problem has resulted in most management agencies being reluctant to introduce species that are new to their states. The last authorized introduction of a new fish species in Wyoming was flathead catfish *Pylodictis olivaris* (Rafinesque, 1818) in the North Platte River in 1993 (Wyoming Wildlife News, 2004). The species did not become established and no further introductions have occurred. The last new species intentionally introduced by management agencies in other western states include cisco *Coregonus artedi* (Lesueur, 1818) in Montana in 1984 (Montana Fish, Wildlife & Parks, 2018b), arctic charr *Salvelinus alpinus* (Linnaeus, 1758) in Colorado in 1990 (Olsen, 2014), and gizzard shad *Dorosoma cepedianum* (Lesueur, 1818) in Utah in 1990 (Sigler & Sigler, 1996). Today, when fisheries agencies introduce new taxa for sport reasons or for biological control, they increasingly use sterile taxa such as tiger muskellunge, splake, tiger trout *Salvelinus fontinalis* × *Salmo trutta*, and triploid grass carp *Ctenopharyngodon idella* (Valenciennes in Cuvier and Valenciennes, 1844) (Kolar et al., 2010). These species do not reproduce and thus do not create beachheads for future invasions.

In summary, illegal stockings and secondary spread via colonization are the major pathways for unauthorized fish introductions in Wyoming and throughout the western United States. Whereas introductions of fish species are now carefully scrutinized by management biologists, the ongoing problem of illegal introductions indicates that we still have much work to do in helping the public realize the negative consequences that arise from these introductions.

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References

Baxter, G. T. & M. D. Stone, 1995. Fishes of Wyoming. Wyoming Game and Fish Department, Cheyenne.

Bradshaw, W. H., 2006. Alpine Lakes Fisheries Surveys in the Cloud Peak Wilderness, Bighorn Mountains, Wyoming: 1987–1998. Wyoming Game and Fish Department, Administrative Report SN00-01-8802. Cheyenne.

Carey, M. P., B. L. Sanderson, T. A. Friesen, K. A. Barnas & J. D. Olden, 2011. Smallmouth bass in the Pacific Northwest: a threat to native species; a benefit for anglers. Reviews in Fisheries Science 19: 305–315.

Chapman D. C. & M. H. Hoff, 2011. Invasive Asian Carps in North America. American Fisheries Society Symposium 74, Bethesda: 163–174.

Cooper, E. L., 1987. Carp in North America. American Fisheries Society, Bethesda.

Correa, C. & M. R. Gross, 2008. Chinook salmon invade southern South America. Biological Invasions 10: 615–639.

Courtenay Jr., W. R. & C. R. Robins, 1975. Exotic organisms: an unsolved, complex problem. BioScience 25: 306–313.

Davies, G. D., R. E. Gozlan & J. R. Britton, 2013. Can accidental introductions of non-native species be prevented by fish stocking audits? Aquatic Conservation: Marine and Freshwater Ecosystems 23: 366–373.

Diez, J. M., C. M. D'Antonio, J. S. Dukes, E. D. Grosholz, J. D. Olden, C. J. B. Sorte, D. M. Blumenthal, B. A. Bradley, R. Early, I. Ibáñez, S. J. Jones, J. J. Lawler & L. P. Miller, 2012. Will extreme climatic events facilitate biological invasions? Frontiers in Ecology and the Environment 10: 249–257.

Drake, D. A. R., R. Mercader, T. Dobson & N. E. Mandrak, 2015. Can we predict risky human behaviour involving invasive species? A case study of the release of fishes to the wild. Biological Invasions 17: 309–326.

Fredenberg, C. R., C. C. Muhlfeld, C. S. Guy, V. S. D'Angelo, C. C. Downs & J. M. Syslo, 2017. Suppression of invasive lake trout in an isolated backcountry lake in Glacier National Park. Fisheries Management and Ecology 24: 33–48.

Gardunio, E. I., C. A. Myrick, R. A. Ridenour, R. M. Keith & C. J. Amadio, 2011. Invasion of illegally introduced burbot in the upper Colorado River Basin, USA. Journal of Applied Ichthyology 27(Suppl 1): 36–42.

Gozlan, R. E., J. R. Britton, I. Cowx & G. H. Copp, 2010. Current knowledge on non-native freshwater fish introductions. Journal of Fish Biology 76: 751–786.

Gray, Q. Z., D. J. Fraser & J. W. A. Grant, 2014. Extirpation for conservation: applying predictors of extinction risk to eradicate introduced trout populations for restoration. Ecological Restoration 32: 59–67.

Harig, A. L., K. D. Fausch & M. K. Young, 2000. Factors influencing success of greenback cutthroat trout translocations. North American Journal of Fisheries Management 20: 994–1004.

Jacobs, A. I. & R. P. Keller, 2017. Straddling the divide: invasive aquatic species in Illinois and movement between the Great Lakes and Mississippi basins. Biological Invasions 19: 635–646.

Johnson, B. M., R. Arlinghaus & P. J. Martinez, 2009. Are we doing all we can to stem the tide of illegal fish stocking? Fisheries 34: 389–394.

Keller, R. P., P. Ermgassen & D. C. Aldridge, 2009. Vectors and timing of freshwater invasions in Great Britain. Conservation Biology 23: 1526–1534.

Kerr, S. J., C. S. Brousseau & M. Muschett, 2005. Invasive aquatic species in Ontario, a review and analysis of potential pathways for introduction. Fisheries 30: 21–30.

Klein, Z. B., M. C. Quist, D. T. Rhea & A. C. Senecal, 2016. Population characteristics and the suppression of nonnative burbot. North American Journal of Fisheries Management 36: 1006–1017.

Knapp, R. A., D. M. Boiano & V. T. Vredenburg, 2007. Removal of nonnative fish results in population expansion of a declining amphibian (mountain yellow-legged frog, *Rana muscosa*). Biological Conservation 135: 11–20.

Koel, T. M., P. E. Bigelow, P. D. Doepke, B. D. Ertel & D. L. Mahony, 2005. Nonnative lake trout result in Yellowstone cutthroat trout decline and impacts to bears and anglers. Fisheries 30: 10–19.

Koenig, M. K., K. A. Meyer, J. R. Kozfkay, J. M. DuPont & E. B. Schriever, 2015. Evaluating the ability of tiger muskellunge to eradicate brook trout in Idaho alpine lakes. North American Journal of Fisheries Management 35: 659–670.

Kolar, C. S., W. R. Courtenay, Jr. & L. G. Nico, 2010. Managing undesired and invading fishes. In: Hubert, W. A. & M. C. Quist (eds), Inland Fisheries Management in North America, 3rd edn. American Fisheries Society, Bethesda: 213–259.

Kornis, M. S., B. C. Weidel, S. M. Powers, T. Cline, M. Diebel, J. Fox & J. F. Kitchell, 2015. Fish community dynamics following dam removal in a fragmented agricultural stream. Aquatic Sciences 77: 465–480.

Lapointe, N. W. R., P. L. Fuller, M. Neilson, B. R. Murphy & P. L. Angermeier, 2016. Pathways of fish invasions in the Mid-Atlantic region of the United States. Management of Biological Invasions 7: 221–233.

Lever, C., 2011. Acclimatization Societies. In Simberloff, D. & M. Rejmánek (eds), Encyclopedia of Biological Invasions. University of California Press, Berkeley: 1–4.

Lorenzen, K., 2014. Understanding and managing enhancements: why fisheries scientists should care. Journal of Fish Biology 85: 1807–1829.

Madsen, D. H., 1937. Protection of native fishes in the national parks. Transactions of the American Fisheries Society 66: 395–397.

Mavrakis, P. H. & D. L. Yule, 1998. North Platte Comprehensive Fisheries Studies: Creel Survey and Stocking Evaluation, 1995–1996. Wyoming Game and Fish Department, Fish Division, Cheyenne.

McMahon, T. E. & D. H. Bennett, 1996. Walleye and Northern Pike: boost or bane to Northwest fisheries. Fisheries 21: 6–13.

Meronek, T. G., P. M. Bouchard, E. R. Buckner, T. M. Burri, K. K. Demmerly, D. C. Hatleli, R. A. Klumb, S. H. Schmidt & D. W. Coble, 1996. A review of fish control projects. North American Journal of Fisheries Management 16: 63–74.

Montana Fish, Wildlife & Parks, 2018a. Montana Fishing Regulations. http://fwp.mt.gov/fishing/regulations/. Accessed 9 March 2018.

Montana Fish, Wildlife & Parks, 2018b. Montana Field Guide – Cisco. http://fieldguide.mt.gov/speciesDetail.aspx?elcode=AFCHA01020. Accessed 8 March 2018.

Munro, A. R., T. E. McMahon & J. R. Ruzycki, 2005. Natural chemical markers identify source and date of introduction of an exotic species: lake trout (*Salvelinus namaycush*) in Yellowstone Lake. Canadian Journal of Fisheries and Aquatic Sciences 62: 79–87.

Nico, L. G., J. D. Williams & H. L. Jelks, 2005. Black Carp: Biological Synopsis and Risk Assessment of an Introduced Fish. Special Publication 32. American Fisheries Society, Bethesda, MD.

Nuñez, M. A., S. Kuebbing, R. D. Dimarco & D. Simberloff, 2012. Invasive species: to eat or not to eat, that is the question. Conservation Letters 5: 334–341.

Obrecht, J., 2004. Angler shatters flathead catfish record. Wyoming Wildlife News 14(1): 7. Published by the Wyoming Game and Fish Department, Cheyenne.

Olsen, D. M., 2014. Arctic char *Salvelinus alpinus* can enhance fisheries in reservoirs with trophic constraints. Master of Science Thesis, Colorado State University, Fort Collins.

Ortega, J. C., H. F. Julio Jr., L. C. Gomes & A. A. Agostinho, 2015. Fish farming as the main driver of fish introductions in Neotropical reservoirs. Hydrobiologia 746: 147–158.

Pasko, S. & J. Goldberg, 2014. Review of harvest incentives to control invasive species. Management of Biological Invasions 5: 263–277.

Paul, A. J., J. R. Post & J. D. Stelfox, 2003. Can anglers influence the abundance of native and nonnative salmonids in a stream from the Canadian Rocky Mountains? North American Journal of Fisheries Management 23: 109–119.

Peterson, D. P., K. D. Fausch, J. Watmough & R. A. Cunjak, 2008. When eradication is not an option, modeling strategies for electrofishing suppression of nonnative brook trout to foster persistence of sympatric native cutthroat trout in small streams. North American Journal of Fisheries Management 28: 1847–1867.

Pister, E., 2001. Wilderness fish stocking: history and perspective. Ecosystems 4: 279–286.

Pratt, T. C., L. M. O'Connor, A. G. Hallett, R. L. McLaughlin, C. Katopodis, D. B. Hayes & R. A. Bergstedt, 2009. Balancing aquatic habitat fragmentation and control of invasive species: enhancing selective fish passage at sea lamprey control barriers. Transactions of the American Fisheries Society 138: 652–665.

Rahel, F. J., 1997. From Johnny Appleseed to Dr. Frankenstein: changing values and the legacy of fisheries management. Fisheries 22: 8–9.

Rahel, F. J., 2000. Homogenization of fish faunas across the United States. Science 288: 854–856.

Rahel, F. J., 2004. Unauthorized fish introductions: fisheries management of the people, for the people, or by the people? In Nickum, M. J., P. M. Mazik, J. G. Nickum & D. D. MacKinlay (eds), Propagated Fishes in Resource Management, American Fisheries Society, Symposium 44. American Fisheries Society, Bethesda: 431–444.

Rahel, F. J., 2013. Intentional fragmentation as a management strategy in aquatic systems. BioScience 63: 362–372.

Rahel, F. J., 2016. Changing philosophies of inland fisheries management as illustrated by the history of angling regulations in Wyoming. Fisheries 41: 38–48.

Remmick, R., 1982. Live bait can kill a fishery. Wyoming Wildlife 46: 30–31.

Shafland, P. L., K. B. Gestring & M. S. Stanford, 2008. Florida's exotic freshwater fishes – 2007. Florida Scientist 71: 220–245.

Shepard, B., R. Spoon & L. Nelson, 2002. A native westslope cutthroat trout population responds positively after brook trout removal and habitat restoration. Intermountain Journal of Sciences 8: 191–211.

Sigler, W. F. & J. W. Sigler, 1996. Fishes of Utah: A Natural History. University of Utah Press, Salt Lake City.

Spratt, R. W., 1946. Rough and forage fish. State of Wyoming, Biennial Report of the Wyoming Game and Fish Commission, 1945–1946. Wyoming Game and Fish Department, Cheyenne: 3 p.

Strecker, A. L., P. M. Campbell & J. D. Olden, 2011. The aquarium trade as an invasion pathway in the Pacific Northwest. Fisheries 36: 74–85.

Syslo, J. M., C. S. Guy, P. E. Bigelow, P. D. Doepke, B. D. Ertel & T. M. Koel, 2011. Response of non-native lake trout (*Salvelinus namaycush*) to 15 years of harvest in Yellowstone Lake, Yellowstone National Park. Canadian Journal of Fisheries and Aquatic Sciences 68: 2132–2145.

Trushenski, J., T. Flagg & C. Kohler, 2010. Use of hatchery fish for conservation, restoration, and enhancement of fisheries. In Hubert, W. A. & M. C. Quist (eds), Inland Fisheries Management in North America. American Fisheries Society, Bethesda: 261–293.

U.S. Fish and Wildlife Service, 2009. Procedures for Stocking Nonnative Fish Species in the Upper Colorado River Basin. Upper Colorado River Endangered Fish Recovery Program, Denver.

Utah Division of Wildlife Resources, 2018. Utah Fishing Guidebook. https://wildlife.utah.gov/guidebooks/2018_pdfs/2018_fishing.pdf. Accessed 9 March 2018.

Vinson, M. R., E. C. Dinger & D. K. Vinson, 2010. Piscicides and invertebrates: after 70 years, does anyone really know? Fisheries 35: 61–71.

Williams, S., E. Winther & C. M. Barr. 2016. Report on the predation index, predator control fisheries, and program evaluation for the Columbia River basin northern pikeminnow sport reward program, 2016. Annual Report. Pacific States Marine Fisheries Commission. http://www.pikeminnow.org/wp-content/uploads/2017/03/2016-Pikeminnow-AR.pdf. Accessed 8 August 2017.

Wiltzius, W. J., 1985. Fish culture and stocking in Colorado, 1872–1978. Division Report No. 12. Colorado Division of Wildlife, Denver, CO.

Wolff, B. A., B. M. Johnson, A. R. Breton, P. J. Martinez & D. L. Winkelman, 2012. Origins and movements of invasive piscivores determined from the strontium isotope ($^{87}Sr/^{86}Sr$) ratio of otoliths. Canadian Journal of Fisheries and Aquatic Sciences 69: 724–739.

Wyoming Game and Fish Department, 1990. Annual Fisheries Progress Report on the 1990 Work Schedule. Wyoming Game and Fish Department, Fish Division, Cheyenne.

Wyoming Game and Fish Department, 2016. Annual Fisheries Progress Report on the 2016 Work Schedule. Wyoming Game and Fish Department, Fish Division, Cheyenne.

Wyoming Game and Fish Department, 2018. Wyoming Fishing Regulations 2018. https://wgfd.wyo.gov/regulations#Fish. Accessed 9 March 2018.

Zelasko, K. A., K. R. Bestgen, J. A. Hawkins & G. C. White, 2016. Evaluation of a long-term predator removal program: abundance and population dynamics of invasive northern pike in the Yampa River, Colorado. Transactions of the American Fisheries Society 145: 1153–1170.