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Research Article

Temporal trends in non-native fishes established in the continental United States

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Abstract

Management of non-native fish species is informed by monitoring their temporal and spatial distribution. There are few published analyses of temporal patterns of established non-native fish species. The objective of this study was to examine the utility of the American Fisheries Society's (AFS) lists of fish names for quantifying trends in the number of established non-native fishes as a first step in determining trends in the number of invasive fish species in the continental United States. As of the 2013 AFS list, there were 66 non-native species listed as established in the continental U.S., a 2.5-fold linear increase from 1970. All of the species, except two, established before 2013 persisted in 2013. The number of species added to each subsequent list increased throughout the period. Eight species were added from 1970 to 1980, 14 from 1980 to 1991, 18 from 1991 to 2004, and 5 from 2004 to 2013. The number of listed non-native families increased linearly from 8 to 19 during the same period. Cichlids, cyprinids, and poeciliids were the most represented families (about 73% of the established species listed in 1970, 1980, and 1991, and about 56% on the 2004 and 2013 lists). Converting the trend in the number of non-native species into the number of invasive species is difficult because of lack of available impact information and the dependency on human perception and value.

Key words: non-native fish, temporal trends, American Fisheries Society

Introduction

Humans affect aquatic ecosystems through intentional and unintentional introductions of species beyond their native range. When human-introduced, non-native species become established they change the ecology of their non-native range (Lockwood et al. 2013). Humans then impose value judgments (e.g., benign, undesirable, harmful, or beneficial) on the impacts of those changes to guide potential management responses. For example, impacts like reduced natural biodiversity, habitat modification, increased disease, and decreased human economies and health are considered harmful (Olden and Poff 2005; Dudgeon et al. 2006; Rahel 2007; Pfeiffer and Voeks 2008). The United States government defines invasive species as non-native to a particular ecosystem (complex of a community of organisms and its environment) capable of propagation whose introduction by humans does or is likely to cause economic or environmental harm or harm to human health (National Invasive Species Council 2014). This definition recognizes that society does not pre-judge a non-native species as necessarily invasive. Beneficial impacts like increased food production, new or improved sport fisheries, biological control of other invasive species, enhanced ornamental industry, or increased species richness may also occur (Clarkson et al. 2005; Sagoff 2005; Galil 2007; Gozlan 2008). These non-native species may or may not be considered invasive.

Lockwood et al. (2003) provided a useful five-stage model for studying the process by which non-native species may be considered invasive. A non-native species is transported and introduced by humans beyond its native range, becomes established, spreads, and has human-perceived negative impacts. UNEP (2008) suggested that "trends in invasive alien species" is a promising indicator of threats to ecosystems, and "number of invasive alien species in each country" may be a measure of the indicator. At the very least, these data might quantify the success of efforts to impede invasions by "keeping them out" (Simberloff et al. 2005). It is useful, therefore, to monitor the global distribution and impacts of non-native species to minimize harmful risks and capitalize on benefits of future introductions (Crossman 1991; Olden and Poff 2005). But, there are few published analyses of temporal patterns in established non-native fish species (Cohen and Carlton 1998; Lockwood et al. 2013).

Although there are some temporal data on non-native fish **introduced** into the U.S. (e.g., Nico and Fuller 1999; Fuller et al. 1999; Fuller 2003 for freshwater species), the number of invasive (i.e., harmful) fish species **established** in the U.S. is unknown. The rate of increase of **established** non-native fish species in the U.S., a necessary first step in determining trends in the number of invasive species in the U.S., has not been quantified. Courtenay and Hensley (1980) reported an exponential trend in the number of **established** non-native fish species (not restricted to invasive species) in North America from 1 in 1680 to 35 in 1980. Although they did not provide data for the U.S. separate from Canada, Welcome (1988) reported that 70 non-native fish species had been **introduced** into the continental U.S. by 1985, and 45 species had become **established** by 1989 (Crossman 1991). However, Nico and Fuller (1999) reported that 38 foreign freshwater species had become **established** in U.S. open waters by 1998 (an apparent decrease of 7 species in 10 years).

Data contained in the American Fisheries Society (AFS) lists of fish names may be useful in addressing this inadequacy. AFS has periodically published lists of non-native fishes established in the continental U.S. since the 1940s after forming the Committee on Common and Scientific Names of Fishes in 1948 (American Fisheries Society 1948). The Committee developed a list of common names of fishes occurring in the continental U.S. and Canada corresponding to accepted scientific names to achieve nomenclature uniformity. The only non-native species included in the first list were "Introduced Carps" (goldfish *Carassius auratus* (Linnaeus, 1758), carp *Cyprinus carpio* Linnaeus, 1758, and tench *Tinca tinca* (Linnaeus, 1758)). The Second Edition (American Fisheries Society 1960) included all native and successfully introduced species without distin-guishing between the two groups. Since 1960, the lists have been updated five times (about every 10 years) and have identified separately native and non-native fish species established in each of the continental U.S. and Canada. The objective of this study was to use the AFS lists to quantify temporal trends in the number of established non-native fish species in the continental U.S.

Methods

The AFS editions of "Common and Scientific Names of Fishes from the United States and Canada" (Bailey et al. 1970; Robins et al. 1980, 1991; Nelson et al. 2004; Page et al. 2013) were used to tabulate, by year, all species listed as "Introduced" (species not native to the U.S. that are established within the geographic areas to which each list applied) into the continental U.S.. The AFS definition of "introduced" includes those species which are "established." Therefore, I use the term "established" instead of "introduced" (i.e., species introduced but not established are not included). The 1970 and 1980 lists did not specify whether introduced fish were introduced into the U.S. or Canada or both, but later editions did. Information in the later editions was used to infer whether or not earlier introductions were applicable to the U.S. The number of species and families listed in each AFS edition were counted, and temporal trends of species and families were deter-mined by fitting regressions using standard linear regression techniques (Draper and Smith 1966).

Results

There were 66 non-native fish species, representing 19 families, listed by AFS in 2013 as established in the continental U.S., about 2.5 times more than were listed in 1970 (Table 1). The number of species of non-native fishes increased linearly during the period 1970 through 2013, from 26 to 66 (Figure 1). The temporal trend is expressed as:

$$Y = -1938 + 0.997X$$

where Y = number of species and X = year. The regression explained 97.7% of the variation in the data (adjusted R^2). The correlation between species and time was very high because all but five species included on any AFS list remained on all subsequent lists. Banded cichlid *Cichlosoma severum* (Heckel, 1840), was included on all lists except the 1991 list. Two species (bairdiella *Bairdiella icistia* (Jordan and Gilbert, 1882) and orangemouth corvina *Cynoscion xanthulus* (Jordan and Gilbert, 1882)) listed before 2013 were extirpated in about 2006 from the Salton Sea, California, by increasing salinity and not included on the 2013 list (Page et al. 2013). Two unidentified species of Locariidae listed in 1991 were apparently re-identified as *Pterygoplichthys* spp. in 2004 (Nelson et al. 2004).

Table 1. List of fishes established in the continental United States (X) as of each of five reporting years (from American Fisheries Society lists of Accepted Common and Scientific Names).

Family	Scientific name	Common name	1970	1980	1991	2004	2013
Callichthyidae	*Hoplosternum littorale* (Hancock, 1828)	Brown hoplo				X	X
Channidae	*Channa marulius* (Hamilton, 1822)	Bullseye Snakehead				X	X
Channidae	*Channas argus* (Canntor, 1842)	Northern Snakehead					X
Cichlidae	*Amphilphus citrinellus* (Gunter, 1867)	Midas Cichlid			X	X	X
Cichlidae	*Astronotus ocellatus* (Agassiz, 1831)	Oscar	X	X	X	X	X
Cichlidae	*Cichla ocellaris* Bloch & Schneider, 1801	Butterfly Peacock Bass			X	X	X
Cichlidae	*Cichlaosoma bimaculatum* (Linnaeus, 1758)	Black Acara	X	X	X	X	X
Cichlidae	*Cichlasoma nigrofasciatum* (Gunther, 1867)	Convict Cichlid	X	X	X	X	X
Cichlidae	*Cichlasoma severum* (Heckel, 1840)	Banded Cichlid	X	X		X	X
Cichlidae	*Cichlasoma urophthalmus* (Gunther, 1862)	Mayan Cichlid			X	X	X
Cichlidae	*Geophagus surinamensis* (Bloch, 1791)	Redstriped Eartheater			X	X	X
Cichlidae	*Hemichromis letourneuxi* Sauvage, 1880	African Jewelfish	X	X	X	X	X
Cichlidae	*Oreochromis aureus* (Steindachner, 1864)	Blue Tilapia		X	X	X	X
Cichlidae	*Oreochromis mossambicus* (Peters, 1852)	Mozambique Tilapia	X	X	X	X	X
Cichlidae	*Oreochromis niloticus* (Linnaeus, 1758)	Nile Tilapia				X	X
Cichlidae	*Oreochromis urolepis* (Norman, 1922)	Wami Tilapia			X	X	X
Cichlidae	*Parachromis managuensis* (Gunther, 1867)	Jaguar Guapote			X	X	X
Cichlidae	*Parachromis salvini* (Gunther, 1862)	Yellowbelly Cichlid				X	X
Cichlidae	*Rosio octofasciatum* (Regan, 1903)	Jack Dempsey		X	X	X	X
Cichlidae	*Sarotherodon melanotheron* Ruppell, 1852	Blackchin Tilapia	X	X	X	X	X
Cichlidae	*Thorichthys meeki* Brind, 1918	Firemouth Cichlid [b]			X	X	X
Cichlidae	*Tilapia mariae* (Boulenger, 1899)	Spotted Tilapia		X	X	X	X
Cichlidae	*Tilapia zilli* (Gervais, 1848)	Redbelly Tilapia		X	X	X	X
Clariidae	*Clarias batrachus* (Linnaeus, 1758)	Walking Catfish	X	X	X	X	X
Cobitidae	*Misgurnus anguillicaudatus* (Cantor, 1842)	Oriental Weatherfish	X	X	X	X	X
Cyprinidae	*Carassius auratus* (Linnaeus, 1758)	Goldfish	X	X	X	X	X
Cyprinidae	*Ctenopharyngodon idella* (Cuvier & Valenciennes, 1844)	Grass Carp		X	X	X	X
Cyprinidae	*Cyprinus carpio* Linnaeus, 1758	Common Carp	X	X	X	X	X
Cyprinidae	*Hypophthalmichthys molitrix* (Valenciennes, 1844)	Silver Carp				X	X
Cyprinidae	*Hypophthalmichthys nobilis* (J. Richardson, 1845)	Bighead Carp			X	X	X
Cyprinidae	*Leuciscus idus* (Linnaeus, 1758)	Ide	X	X	X	X	X
Cyprinidae	*Mylopharyngodon piceus* (Richardson, 1846)	Black Carp					X
Cyprinidae	*Rhodeus sericeus* (Pallas, 1776)	Bitterling	X	X	X	X	X
Cyprinidae	*Scardinius erythrophthalmus* (Linnaeus, 1758)	Rudd	X	X	X	X	X
Cyprinidae	*Tinca tinca* (Linnaeus, 1758)	Tench	X	X	X	X	X
Cyprinodontidae	*Rivulus hartii* (Boulenger, 1890)	Giant Rivulus			X	X	X
Doradidae	*Platydoras armatulus* (Valenciennes, 1840)	Southern Striped Raphael				X	X
Gobiidae	*Acanthogobius flavimanus* (Temminck and Schlegel, 1845)	Yellowfin Goby	X	X	X	X	X
Gobiidae	*Neogobius melanostomus* (Pallas, 1814)	Round Goby				X	X
Gobiidae	*Proterorhinus marmoratus* (Pallas, 1814)	Tubenose Goby				X	X
Gobiidae	*Tridentiger barbatus* (Gunther, 1861)	Shokihaze Goby				X	X
Gobiidae	*Tridentiger bifasciatus* Steindachner, 1881	Shimofuri Goby				X	X
Gobiidae	*Tridentiger trigonocephalus* (Gill, 1858)	Chameleon Goby	X	X	X	X	X
Loricariidae	*Hypostomus plecostomus* (Linnaeus, 1758)	Suckermouth Catfish		X	X	X	X
Loricariidae	*Hypostomus* sp. (1)a	Suckermouth Catfish			X		
Loricariidae	*Hypostomus* sp. (2)a	Suckermouth Catfish			X		
Loricariidae	*Pterygoplichthys anisitsi* Eigenmann & Kennedy, 1903	Southern Sailfin Catfish				X	X
Loricariidae	*Pterygoplichthys disjunctivus* (Weber, 1991)	Vermiculated Sailfin Catfish				X	X
Loricariidae	*Pterygoplichthys multiradiatus* (Hancock, 1828)	Orinoco Sailfin Catfish			X	X	X
Loricariidae	*Pterygoplichthys pardalis* (Castelnau, 1855)	Amazon Sailfin Catfish				X	X
Mastacembelidae	*Macrognathus siamensis* (Gunther, 1861)	Spotfin Spiny Eel					X
Notopteridae	*Chitala ornata* (Gray, 1831)	Clown Knifefish				X	X
Osmeridae	*Hypomesus nipponensis* McAllister, 1963	Wakasagi		X	X	X	X
Osphronemidae	*Trichopsis vitata* (Cuvier, 1831)	Croaking Gouramy			X	X	X
Percidae	*Gymnocephalus cernuus* (Linnaeus, 1758)	Ruffe			X	X	X
Percidae	*Sander lucioperca* (Linnaeus, 1758)	Zander					X

Table 1 (continued).

Family	Scientific name	Common name	1970	1980	1991	2004	2013
Poeciliidae	*Belonesox belizanus* (Kner, 1860)	Pike Killifish	X	X	X	X	X
Poeciliidae	*Poecilia mexicana* Steindachner, 1863	Shortfin Molly	X	X	X	X	X
Poeciliidae	*Poecilia reticulata* Peters, 1859	Guppy	X	X	X	X	X
Poeciliidae	*Poecilia sphenops* Valenciennes, 1846	Mexican Molly				X	X
Poeciliidae	*Poeciliopsis gracilis* Valenciennes, 1846	Porthole Livebearer		X	X	X	X
Poeciliidae	*Xiphophorus helleri* Heckel, 1848	Green Swordtail	X	X	X	X	X
Poeciliidae	*Xiphophorus maculatus* (Gunther, 1866)	Southern Platyfish	X	X	X	X	X
Poeciliidae	*Xiphophorus variatus* (Meek, 1904)	Variable Platyfish	X	X	X	X	X
Salmonidae	*Salmo trutta* Linnaeus, 1758	Brown Trout	X	X	X	X	X
Sciaenidae	*Bairdiella icistia* (Jordan and Gilbert, 1882)	Bairdiella	X	X	X	X	
Sciaenidae	*Cynoscion xanthulus* (Jordan and Gilbert, 1882)	Orangemouth Corvina	X	X	X	X	
Scorpaenidae	*Pteros miles* (Bennett, 1828)	Devil Firefish					X
Scorpaenidae	*Pteros volitans* Linnaeus, 1758	Red Lionfish				X	X
Synbranchidae	*Monopterus albus* (Zuiew, 1793)	Asian Swamp Eel				X	X
Total number of families			8	10	13	19	19
Total number of species			26	34	47	63	66

[a]*Hypostomus* sp. 1 and 2 re-identified as *Pterygoplichthys* spp.

[b]Information received after the 1980 list was in press indicated firemouth cichlid was established in Florida.

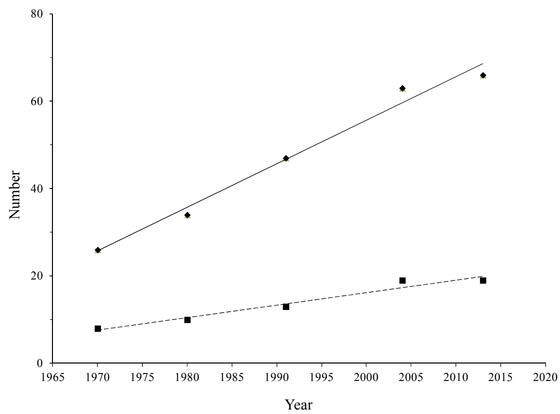

Figure 1. Number of non-native fish species (♦) and families (■) included on AFS lists of established fishes in the continental United States from 1970 through 2013.

The number of new species added to each list, compared to the previous list, increased throughout the study period except for the 2013 list (compared to the 2004 list). Five new species were added from 2004 to 2013. In contrast, eight species were added from 1970 to 1980, 14 from 1980 to 1991, and 18 from 1991 to 2004 (Table 1).

Almost all non-native fish species were established in fresh water. Three species (chameleon goby *Tridentiger trigonocephalus* (Gill, 1858), red lionfish *Pterois volitans* Linnaeus, 1758, and devil *firefish P. miles* (Bennett, 1828)) were not. The chameleon goby occurs in estuaries, and both Pterois spp. occur in the Atlantic Ocean and Gulf of Mexico.

The diversity of the families represented in the non-native fish community also increased about 2.5 times from 1970 through 2013 (Figure 1). The temporal trend is expressed as:

$$Y = -554 + 0.285X$$

where Y = number of families and X = year. The regression explained 94.4% of the variation in the data (adjusted R^2). Cichlids, cyprinids, and poeciliids were the most represented families during the 43-year record (Table 1). These three families accounted for 73% of the established species listed in1970, 1980, and 1991, and about 56% of the species on the 2004 and 2013 lists. The family with the most species was cichlidae. They accounted for the most species on each list, increasing from 7 species in 1970 to 20 in 2013.

Discussion

The AFS lists of common and scientific names of fishes provide a baseline of data necessary to monitor quantitatively the number of non-native fish species established in the continental U.S. (about 10 species per decade). Incorporating temporal trends presented in this paper into future AFS editions would be an efficient way to monitor retrospective temporal trends in the number of non-native fish species in the continental U.S. Since the lists are updated about every 10 years, they do not inform intra-decadal changes and they do not provide real-time monitoring of newly established species. For example, the lists do not include species that might have become established and then extirpated during the years between consecutively published lists. Data collected continuously by the U.S. Fish and Wildlife Service, especially for freshwater fish, (Nico and Fuller 1999; Fuller 2003) may be useful for refining and improving precision of estimates in this study. For example, data in the U.S. Geological Survey Nonindigenous Aquatic Species database indicated about eight 8 new non-native fish species reportedly established per decade (P. Fuller, U.S. Geological Survey, personal communication) as compared to the estimated 10 species/decade from this study.

The lists provide limited information on the distribution of non-native fishes within the continental U.S. Hawaii, Alaska, or U.S. Territories were not included (except that the 1991 edition provided a list of exotic fishes established in Hawaiian fresh and marine waters—but these data were not used in this analysis). The 2013 list included information separately for Mexico and Canada. These data could be the foundation for providing temporal trends beyond the continental U.S., and consideration should be given to including additional trend information in future lists.

This study assumes the AFS lists are accurate and complete. Their periodic revision by a committee of subject matter experts using the latest taxonomic information maximizes the likelihood that the assumption is valid. As such, they are reliable sources of information for management of non-native fish, including species identification and verification, risk assessments, prevention and response strategies, surveillance plans, and evaluation of management actions.

AFS also produces lists of names for crustacea, cnidaria/ctenophora, and mollusks. Publications for each of these taxa are only on the second edition, with the first editions published less than 20 years ago. As these lists are updated, they might prove as useful as the lists of fish names in monitoring trends in established populations of non-native species in the U.S.

The increasing trend in the number of known established non-native fishes in the continental U.S. will probably continue into the foreseeable future (DeSilva et al. 2006; Gozlan 2008; Gozlan et al. 2010). The underlying factors most often cited as contributing to geographic spread (i.e., more people in more places with greater demands for natural resources) are not likely to decrease (Miller-Reed and Czech 2005). Expansion of aquaculture and use of non-native species for food and as ornamental fish appears inevitable (Rahel 2007). Further, increased transport, introduction, and establishment of non-native fish are likely as we continue to modify our environment, globalize the economy, and respond to changing climate (Rahel 2000; Dudgeon et al. 2006). It also seems likely that the number of documented established non-native species may also increase as an artifact of increased sampling effort as attention to the impacts of invasive species increases (Lockwood et al. 2013).

The future rate of increase in newly established non-native fishes in the U.S. may, however, decrease. Fewer new species were established in the continental U.S. between 2004 and 2013 than during any previous consecutive period. This decline might reflect the decreasing support for the use of non-native fish in the U.S., a decrease in the construction of new habitats (i.e., reservoirs), increased management efforts to prevent introductions, or other factors. For example, none of the newly established fish resulted from the intentional stocking to create or maintain any sport fishery, as was done with butterfly peacock bass, orangemouth, or baidiella (Fuller et al. 1999). Only one cyprinid (black carp) was added to the 2013 list, unlike in previous years when several cyprinids were used to control non-native aquatic plants. No new cichlids were included on the 2013 list, possibly indicating improvements in the availability, transport, and distribution of fish used in the fish-hobbyist industry. Additional research is warranted.

Converting trends in non-native fish species into trends in invasive (i.e., harmful) species is difficult (Parker et al. 1999; Lockwood et al. 2013). The effects of many non-native species on individuals, populations, communities and ecosystems have not been studied (Fuller et al. 1999; LePrieur et al. 2009; Cucherouset and Olden 2011). But, even if the effects are known, the nature of the effects with respect to human perception and valuation is a topic of debate (Sagoff 2005; Simberloff 2005; Gozlan et al. 2010; Vitule et al. 2009). Brown and Sax (2007) concluded that although invading species are often accused of damaging the ecosystem structure and function, there is usually little scientific evidence of such negative impacts. Gozlan (2008) estimated that the probability of an ecological impact resulting from freshwater fish introduction is relatively low (around 6%). On the other hand, Sorte et al. (2010) stated that introduced species are recognized as one of the main anthropogenic threats to biological systems. Wilcove et al al. (1998) stated that the spread of alien species (not restricted to fish) is the second greatest threat to biodiversity in the U.S.

Natural biodiversity can enhance ecosystem resiliency and productivity (Lapointe et al. 2014). Most studies examining impacts of non-native fish species on non-human components of ecosystems have focused on natural biodiversity (Raffaelli 2004; Clarkson et al. 2005; Worm et al. 2006; Cucherousset and Olden 2011). The evidence that non-native species are a direct cause of native population decline is not without question (Gozlan et al. 2010). For example, Wilcove et al. (1998) concluded that non-native species are the cause of endangerment for 48% of the species listed under the U.S. Endangered Species Act. But, Brown and Sax (2007) concluded that alien species have undoubtedly contributed to the extinction of some native species, but the ultimate cause of extinction is often ambiguous because other human activities have had substantial environmental impacts. Regardless of the extent to which non-native species may be causing native species extinction, there is little doubt that biotic homogenization (establishment of exotic species coupled with loss of native species) is accelerating (Rahel 2000, 2007; Elvidge and Ricciardi 2007). Fundamental to understanding the impacts of homogenization is an effective non-native species monitoring program, and this study has demonstrated that AFS lists can provide estimates of retrospective inter-decadal trends of established non-native species within the U.S. and potentially Canada and Mexico.

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