FACTORS ASSOCIATED WITH THE DISTRIBUTION AND ABUNDANCE OF NON-NATIVE FISHES IN STREAMS OF THE AMERICAN WEST

by

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Fisheries Research Report 02-04

January, 2004

ACKNOWLEDGEMENTS

Funding for this project was provided by the U.S. Environmental Protection Agency (EPA), Office of Research and Development, through a sub-contract with Lockheed Martin (2001), the U.S. Geological Survey (USGS), Water Resource Division, the University of Arizona, and the Arizona Game and Fish Department through Federal Aid in Sportfish Restoration. Special thanks to Dave Peck, Phil Kaufmann, William Kepner, Thom Whittier, and Robert Hughes of the EPA for additional guidance in study design and analysis, and support from Gail Cordy (USGS). Also thanks to James deVos, and Anthony Robinson from the Arizona Game and Fish Department for project guidance.

We are grateful to Courtney Conway, and William Matter for their vision, support, and review on this project. We also thank Bob Steidl for additional assistance with design considerations and statistical analysis.

We are especially indebted to the dedication of field crew members Nick Paretti, Andrea Francis, David Ward, Paul Matson, and additional help from USGS employees.

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EXECUTIVE SUMMARY

Non-native fish species (organisms found outside their indigenous range) have had a profound impact on the structure and function of ecosystems. Through predation, competition, and hybridization, non-native fishes have contributed to the decline of biological diversity of American stream fauna, and were implicated in 49% of endangered fish species listings (Deacon 1988, Miller et al. 1989, Hughes and Noss 1992, Allen and Flecker 1993, Vitousek et al. 1997, Whittier et al. 1997, D'Antonio and Haubensak 1998, Allen et al. 1999, Waite and Carpenter 2000, Shrader-Frechette 2001). A compilation of over 17,000 records of non-native fishes occurrence reported 536 non-native fish species from 75 taxonomic families, and 6 continents had been introduced in inland waters of the United States (Fuller et al. 1999, Nico and Fuller 1999).

Since the end of the 19th century, streams of the western United States have been the focus of many efforts to introduce new fish species (Nico and Fuller 1999). Because eradication of non-native species often is ineffective or impractical, most non-native species will remain a part of ecosystems, necessitating further study of these organisms to best predict and manage their impact (Mooney and Drake 1989, Carey 1996).

Large-scale studies of aquatic environments, such as the National Water Quality Assessment (NAWQA) program and Environmental Monitoring and Assessment Program (EMAP) - Surface Waters, began recently (Peck et al. 2002, USGS 2003). Access to standardized data from across the American West allows the opportunity to document the distribution and abundance and environmental factors affecting non-native

fish species at a regional scale that could not be approached with studies performed on smaller scales.

Our specific objectives for the first part of the study (Chapter 1) were to: (1) quantify major patterns in the distribution of non-native fishes across the American West and at a statewide level, (2) examine the relationship between biotic, abiotic, and anthropogenic factors and the presence and relative abundance of both native and non-native fishes in streams of the American West to address what evidence there may be for generalized hypotheses of invasion by non-native fishes, and evaluate whether it is appropriate to address such issues on a large scale, and (3) evaluate the scale and relative importance of non-native species and ecosystem alteration on native fish species.

Our specific objectives for the second part of the study (Chapter 2) were to: (1) quantify major patterns in the distribution and relative abundance of 10 non-native fish species (selected based upon their known impact on native fishes, and the extent of their distributions in the American West), and (2) identify which biotic, abiotic, and anthropogenic factors were most closely related to the presence and relative abundance of each selected non-native fish species, to help predict where these species might invade, and predict where they might become abundant. This information will help scientists and managers understand the scope of the distribution of non-native fishes in the western United States, and to develop workable hypotheses in studying the processes or mechanisms involved with invasions of non-native fishes (as a group) on a large scale. Such information also may allow managers to predict where specific introduced species are most likely established and abundant, as well as develop management strategies to control non-native populations and preserve native fish. The highlights of our findings are as follows:

- Native fish species were found in 88.8% (± 2.5%) of stream length that supported fish. Non-native species were found in 50.1% (± 3.9%) of reaches (Figure 2). Almost 1 in every 4 individual fish was non-native (23.1 ± 2.8%), while the remaining portion (76.9 ± 2.9%) were native.
- Streams in southwestern states (AZ, CA, CO, NV, UT) had the greatest representation of non-native fish by percent of species present, percent of stream length in which these species are present, and relative abundance of non-native fishes in the species assemblages. Because these states also have a number of highly endemic and number of threatened and endangered fishes, this region probably requires special consideration in the management of non-native fishes.
- The most widely distributed and abundant non-native fish species in western streams include food and sport fish, as well as a number of cyprinids introduced from bait releases and as forage species. Because the majority of these species continue to be introduced for sport fisheries, further studies should investigate the effects of these species on native fish species. Examination and modification of sport fish stocking and management programs would be important for slowing future invasions in western streams.
- We found non-native fish species to be present in streams influenced by all types of land-use and all levels of human disturbance, however, there were

notable differences in the type of non-native species we found according to land use and level of human disturbance. We found forestlands, that host the least disturbed streams, more likely to host non-native salmonids, while species that are more tolerant of degraded or enriched waters, such as common carp, mosquitofish, centrarchids, and ictalurids, were most common in less pristine streams of agricultural and urban regions.

- Because the type of non-native fishes found varied by land-use and level of human disturbance, it is important that the effects of non-native species be studied at an individual species level. However, there were some general conclusions we could make from the study of non-native fishes as a whole. We found that non-native fish tended to increase in relative abundance in less disturbed streams, although they also were highly abundant in the most disturbed streams (Correlation, $r = 0.23$, $P < 0.01$). Streams in forested lands had the lowest likelihood (43.8 $\pm$ 5.5%) of having non-native fishes.
- Non-native fishes were more likely to be in streams that had a greater number of native fish species (T-test, $t = 1.6$, $P < 0.01$), but less likely to be in streams that had higher densities of native fishes (T-test, $t = -9.4$, $P < 0.01$). Non-native fishes had lower relative abundance in streams that had a high number of native fish species (Correlation, $r = -0.60$, $P < 0.01$) and in streams with higher densities of native fish (Correlation, $r = -0.27$, $P < 0.01$).
- While human disturbance was not associated with the presence of native fishes as a group, native fishes were negatively associated with the presence,

abundance, and density of non-native fishes. Of stream kilometers that hosted native fishes, 24.4% were highly disturbed, while 43.7% hosted non-native fishes. The impact of non-native fishes on native species might be equal or greater than human alteration to ecosystems in the western United States, and should illicit at least equivalent attention in the management of native populations.

- The distribution of many non-native fish species may be best explained by the extent of human efforts to introduce them rather than environmental conditions, while their relative abundance may be more related to the biotic and abiotic conditions of the areas in which they have been introduced.
- Brown trout and rainbow trout were associated with lower order, higher gradient streams with larger substrates, found in regions of forest or rangeland, with cooler temperatures. Non-native salmonids are probably limited to such streams, as their sensitivity to eutrophic conditions, and lower heat tolerance, might preclude them from surviving in the conditions and temperatures found more commonly in other land-uses. Salmonids had the highest relative abundance in many areas, possibly because they are more likely to live in single species assemblages, can feed on a wide variety of prey, and were introduced into many fishless streams.
- Largemouth bass and green sunfish were associated with larger streams with slow moving water, found in more populated regions with warmer temperatures. Centrarchids are typically not tolerant to cold temperatures but

have a higher tolerance of more nutrient enriched systems associated with agricultural streams and urban streams that receive effluent.

- Common carp, fathead minnow, red shiner and mosquitofish, were most associated with larger, more open streams, with slow moving water in more densely populated and disturbed regions. Cyprinids and mosquitofish were most highly associated with warmer January and July temperatures, and may most likely be limited in their distribution by cold temperatures. Mosquitofish are most associated with more urban areas, as would be expected for a species introduced for the control of mosquitoes around populated areas.

Management implications

This information will help identify sites that may be susceptible to certain fish species becoming established and developing high relative abundance, and can help identify variables that might be manipulated to favor native fish species over specific non-native species. Managers can choose to do this in three ways. First, the means and ranges of stream parameters measured and the presence of each species would describe optimal and limits of conditions to which a species may be adapted. Second, the results from individual parameter t-tests and correlations could be used to help evaluate factors related to the potential for a species to become established. Correlations can be used to help predict the relative abundance that a species may attain following an introduction. Third, managers could use models of variables most associated with the presence and abundance of each species to help estimate the outcome of a species introduction. Managers need to collect data for each significant variable, make appropriate transformations, and use these values in the models. The result would be a probability of a species presence at a site, and a percent relative abundance of the species within the assemblage, though this may not be directly transferable to predicting the outcome of an introduction.

Conclusion

Because each non-native fish species has a unique set of adaptations and tolerances, there will likely be no general rules of invasiveness that will prove useful for prediction in specific cases (Shrader-Freschette 2000). Therefore methods to eradicate and suppress non-native fishes may need to be developed from studies of a specific species, though it may be difficult to develop meaningful models of introductions for individual species.

The analysis of large-scale sampling may serve its most useful purpose as a warning, implicating the need to educate not only fisheries managers, but the public as well, about the scale and potential problem now posed by non-native fish species in western streams.

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CHAPTER 1

Patterns in distribution and abundance of non-native fishes

in streams of the American West

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Abstract **-** Non-native fish species have been implicated in native fish extinction and endangerment in the United States. Access to standardized data from across the American West allowed the opportunity to study the distribution and abundance of native and non-native fish species at a scale that has rarely been approached previously. Non-native fishes comprise 1 of every 4 individual fish in the West and are distributed across 50% of the total length of western streams. The greatest abundance and distribution of non-native fishes is in the southwestern states (AZ, CA, CO, NV, UT). The non-native species with the greatest abundance and distribution were those introduced as sport fishes. We found non-native fishes present in all streams influenced by all types of land-use and all levels of human disturbance, and not positively correlated with human disturbance. Because the type of non-native fishes found varied by land-use and level of human disturbance, it is important that the effects of non-native species be studied at an individual species level. However, there were some general conclusions we could make from the study of non-native fishes as a whole. Non-native species were more commonly

found in communities rich in native species, while the presence and density of non-native fishes was negatively associated with the presence and relative abundance of native fish species. Of stream kilometers that hosted native fishes, 24.4% were highly disturbed, while 43.7% hosted non-native fishes. The impact of non-native fishes on native species might be equal or greater than human alteration to ecosystems in the western United States, and should illicit at least equivalent attention in the management of native populations.

Introduction

Non-native species (organisms found outside their indigenous range) cause an estimated 122 to 138 billion dollars of damage in the United States each year, have significant impact on the structure and function of ecosystems, and contribute to the extinction of species and the decline of biological diversity (Vitousek et al. 1997, D'Antonio and Haubensak 1998, Mack et al. 2000, Shrader-Frechette 2001). A 1999 compilation of over 17,000 records of non-native fishes occurrence reported 536 non-native species in inland waters of the U.S. (Fuller et al. 1999, Nico and Fuller 1999). A study of extinctions of North American fish during a 100-year period (1889-1989) indicates that 40 taxa, including 27 species, 13 subspecies and 3 genera were lost (Miller et al. 1989). Non-native fish species were implicated in 49% of endangered species listings, second only to habitat loss (Wilcove et al. 1998, Magnusson et al. 1998).

Since the end of the 19th century, western streams have been the focus of species introduction efforts. Believing native communities of the West to be depauperate, the

U.S. Fish Commission used the transcontinental railway system to bring eastern species west. The rate of introductions and the number of species introduced has grown since the 1950's with advances in propagation and transportation of species, and the introduction of species from other continents (Nico and Fuller 1999).

Introduced species have impacted the fauna of western streams. Because eradication of non-native species is often ineffective or impractical, most non-native species will remain a part of ecosystems, implicating the need for further study of these organisms to best predict and manage their impact (Mooney and Drake 1989, Carey 1996).

Many studies of non-native fishes have documented the general history of species introductions (Courtenay 1980, Rosenthal 1980, Crossman 1991, Rahel 1997), and assessed the threat and impact of non-native fish species on native fish populations and communities (Whittier et al. 1997, Parker et al. 1999, Whittier and Kincaid 1999, Pascual et al. 2002). Some studies have tried to understand what makes an introduction successful, trying to identify why some species are able to establish, dominate and replace native fauna. These studies have invoked characteristics of species that make them more invasive, citing morphology, species origin, and reproductive strategies (Sax and Brown 2000, Mack et al. 2000, Moller 1996, Sakai et al. 2001, Moyle and Light 1996, Williamson and Fitter 1996, Ross 1991, Lassuy 1995), characteristics of sites that make them more invasible, citing isolation (MacArthur 1970, MacArthur 1972, Moyle and Light 1996, Sax and Brown 2000), and human disturbance or the creation of novel environments (Arthington 1983, Moyle and Light 1996, Saurez 1998, Wilcove et al. 1998, Ross et al. 2001), and characteristics of the biotic community that may allow for resistance to invasion, citing the mechanisms of species packing, empty niche, and competitive exclusion (Elton 1958, MacArthur 1970, MacArthur 1972, Moyle 1986, Case 1990, Pimm 1991, Case 1991, Case 1996, Tilman 1997, Levine and D'Antonio 1999).

Few of these generalized hypotheses have been tested, and often are based upon inferential judgment of qualitative data, much of which may likely be based upon artifacts of the species that have most often been chosen by humans for introduction (Moller 1996, Kolar and Lodge 2002). Many studies have concluded that the outcome of fish introductions is dependant upon characteristics of individual species and the sites to which they are introduced, and that general rules or laws developed to explain invasion may be misleading (Schrader-Frechette and McCoy 1994, Moyle and Light 1996, Rabeni and Sowa 1996, Schrader-Freschette 2001, Kolar and Lodge 2002).

Few studies have examined the concepts of species introductions in a landscape larger than a watershed, or have pooled data from many sources to patch together a larger region for analysis (Moyle and Light 1996, Gido and Brown 1999). Large-scale studies of aquatic environments, such as the National Water Quality Assessment (NAWQA) program and Environmental Monitoring and Assessment Program (EMAP) - Surface Waters, began recently (Peck et al. 2002, USGS 2003). Access to standardized data from across the American West allowed me to document the distribution and abundance of non-native fish species at a regional scale to seek patterns that may not be evident at smaller scales. This data will also allow the evaluation of whether generalized hypotheses about invasion developed from all taxonomic groups, are applicable to a single taxon (fish) in a specific region (western United States).

Specific objectives of this study were to: (1) quantify major patterns in the distribution of non-native fishes across the American West and at a statewide level, (2) examine the relationship between biotic, abiotic, and anthropogenic factors and the presence and relative abundance of both native and non-native fishes in streams of the American West to address what evidence there may be for generalized hypotheses of invasion by non-native fishes, and evaluate whether it is appropriate to address such issues on a large scale, and (3) evaluate the scale and relative importance of non-native species and ecosystem alteration on native fish species.

This information will help managers understand the scope of the distribution of non-native fishes in the western United States. Such information also may allow scientists to develop workable hypotheses in studying the processes or mechanisms involved with invasions of non-native fishes on a large scale.

Methods

Data on the presence and abundance of over 180 fish species and hybrids, and various characteristics of riparian systems in which they were found, were collected from 689 sites during a 3-year (2000-2002) survey across 12 western states (Arizona, California, Colorado, Idaho, Montana, Nevada, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming) (Table 1). Data were collected as part of the U.S. Environmental Protection Agency (EPA) EMAP-Surface Waters program designed to monitor and assess trends, stressors, and status of ecological conditions of flowing waters

(Peck et al. 2001). All sampling crews were trained by EPA personnel in field measures and protocol, and were issued equivalent gear to ensure standardization of all measures.

Sample sites were chosen by a stratified random selection from all reaches of perennial stream identified on 1:100,000 scale USGS maps, excluding the main stems of the Colorado, Columbia, Snake and Missouri rivers, as these rivers were too large to be sampled using the protocol. The sample population was weighted such that sites within each strata represented the size of the strata, resulting in estimates that represent conditions for all western streams (>650,000 km).

The reach of stream surveyed at each site was equal to 40 times the channel width, with a minimum length of 150 m. The reach length was determined to ensure the capture of ≥ 90% of the fish species present. Crews used a backpack electrofishing unit to perform a single upstream pass (total shocking time = 45 to 180 min depending upon the size of the stream) through a reach to sample fish, with an effort to sample all habitats present in proportion to their size. Species and numbers of individuals were recorded for each site. The Smithsonian Institution was provided voucher samples of species collected in the field to verify field identification (Peck et al. 2001).

Presence and relative abundance were used for the analyses of non-native fishes to represent the positive success of a species introduction, and as a measure of the level of success or predominance of non-native fish in a fish assemblage at each site. Relative abundance of species for each site was estimated by dividing the number of each species captured by the total number of fish captured. Because relative abundance is a percentage of the total number of fish an area sustains, it factors in variation among sites that may affect other measures of fish in an area, such as fish density by area.

Fish origin (native or non-native) was determined for each species by reviewing 15 sources that included information on species range and history in the western states (Churchill and Over 1938, Simon 1951, Bailey and Allum 1962, Minckley 1973, McClane 1974, Wydoski and Whitney 1979, Simpson and Wallace 1982, Page et al. 1991, La Rivers 1994, North Dakota Game and Fish 1994, Holton and Johnson 1996, Sigler and Sigler 1996, Nico and Fuller 1999, Moyle 2002, Nico and Fuller 2003). Native fish were defined as those species that naturally occurred at a site, while non-native fish were defined as a species that was at a site outside of its native range. Native and non-native origin was determined to smallest scale possible (stream, drainage basin, or region).

Species not identified in the field and awaiting identification by the Smithsonian Institution were recorded from 102 sites. If the family was known, and was a family with other congenerics known to be native to the drainage or region, the fish was classified as native. If the family was not likely to be native to a drainage or region, the species was classified as non-native. All fish of unknown species and family (found at 6 sites) were classified as native to give a conservative estimate of the presence of non-native fishes in an assemblage.

Density of native and non-native fishes was calculated by dividing the number of native and non-native fish collected by the surface area of the stream sampled. Surface area was the product of the length of stream in which fish were collected, and the average of channel width taken at five transects across each river.

The landscape surrounding each sampling site was categorized based upon dominant land use and level of human disturbance. The land-use categories were: forest, range, agriculture, suburban/town, and urban. The level of human disturbance was based upon a scale of 1 (totally developed) to 5 (pristine). This determination was a visual assessment of the degree of impact to stream morphology, riparian structure, and water quality, because of human activity.

General and physical site parameters were recorded for each site, including latitude, longitude, and stream order (Strahler classification). Physical parameters measured include channel width and depth (to calculate mean volume).

We used a geographic information system (GIS) to gather data on variables not obtained from the field. Layers of data were imported from various sources and matched to EMAP sites. Average daily temperature change, mean daily January minimum temperature, mean daily July maximum temperature, and mean annual precipitation were based upon 30-year averages (1961 – 1990) from 4,775 temperature stations and 6,662 precipitation stations monitored by the National Oceanic and Atmospheric Administration (NOAA) and compiled by the National Climate Data Center (NCDC 2003). To estimate mean road density and average elevation we used the data associated with surrounding area, based upon a national coverage of a grid of 648 km^2 hexagons developed by the EPA, in which each sample was taken (White et al. 1999). To estimate human density we used the average for the county, based upon the 1995 U.S. Census

Bureau survey, from which each sample was taken (USGS 2002). For all variables, distributions and residuals were checked for outliers and shape, and appropriate transformations were made (Table 1).

We summarized data by state and region, to estimate the representation of native and non-native fishes in the biotic assemblages in streams across the western United States. We examined characteristics of the 10 most widely distributed non-native species and the 10 species with the greatest mean relative abundance at sites at which they are present, to determine if there were any characteristics shared by these species, that might make increase their likelihood of being “invasive.” The characteristics we considered included reason for introduction, trophic level, species origin, body size, reproductive strategy, water quality tolerance, and thermal tolerance. To determine if specific characteristics of a site made it more “invadeable,” we used t-tests and correlations to compare the presence and abundance of non-native fishes with mean road density, mean human population density, degree of human disturbance, and dominant land, to evaluate any relationships between the presence of humans or ecosystem alterations and non-native fishes. To determine if there were specific characteristics of a species assemblage that might make a community more “resistant” to invasion, we used t-tests and correlations to compare the presence and abundance non-native species with native species richness, total species richness, native species density, and stream order, to evaluate relationships of native species richness, and distance of a species assemblage from larger a larger pool of species, and non-native fishes.

To examine the relative importance of the impact on native fishes from ecosystem disturbance and non-native fish species, we used t-tests and correlations of native species presence and relative abundance and the level of human disturbance, dominant land-use, human population, road density, the number of number of non-native fish species, and the density of non-native fishes. We also compared the proportion of stream kilometers hosting native fish species that host non-native fishes, and are found associated with high levels of human disturbance.

Results

Regional Summary

The 689 sample sites represent over 650,000 km of stream. Of this length of stream, 81.2 % (± 2.9; 95% confidence interval) hosted at least 1 fish species, and the remaining 18.8% (± 2.9) apparently were fishless. 180 species were detected across the region; 118 (65.6%) were native throughout the West, 34 (18.8%) were considered to be both native and non-native across their range, and 28 (15.6%) were non-native across the West. Fish assemblages ranged from entirely native to entirely non-native in composition, and hosted 1 to 25 species (Fig. 1).

Fish assemblages made up entirely of native species were found in 49.9% (± 4.0) of stream reaches. Native fish species were found in 88.8% (± 2.5) of stream reaches that supported fish.

Non-native species were found in 50.1% (+ 3.9) of reaches (Figure 2). Fish assemblages made up of entirely non-native fishes were found in 11.2% (+ 2.4) of reaches. Approximately 1 in every 4 individual fish was non-native (23.1 + 2.8).

Statewide Summary

Non-native fishes were detected in over 50% of the stream length of Colorado (72.6 + 13.7%), Montana (68.6 + 20.5%), Arizona (66.7 + 17.0%), Utah (65.8 + 16.5%), North Dakota (60.9 + 15.4%), and South Dakota (53.1 + 14.5%). More than 25% of the stream length in Colorado and Nevada hosts only non-native fishes (Table 2).

In Colorado, which had the highest relative abundance of non-native fish, about 2 of 3 fish were non-native (66.0 + 10.8). Arizona had the second highest relative abundance of non-native fish, and about 1 in 2 individual fish were non-native, while in North Dakota only 1 in 12 fish was non-native (8.2 + 17.3%) (Table 3).

The number of fish species in each state ranged from 21 to 73. Non-native species richness for each state ranged from 3 to 21 species. More than half of the fish, by species detected, in Arizona (59.3%), Colorado (52.8 %) and North Dakota (52.2%) were non-native (Table 4).

The non-native fish species that occupied the greatest portion of stream length were brook trout *Salvelinus fontinalis*, brown trout *Salmo trutta*, rainbow trout *Oncorhynchus ourkiss*, common carp *Cyprinus carpio*, smallmouth bass *Micropterus dolomieu*, largemouth bass *M. salmoides*, green sunfish *Lepomis cyanellus*, fathead minnow

Pimephales promelas, yellow perch *Perca flavescens*, and yellow bullhead *Ameiurus natalis* (Table 5).

The non-native fish with the greatest relative abundance in streams across the states were, brook trout, cutthroat trout *O. clarki*, mosquitofish *Gambusia affinis*, golden shiner *Notemigonous crysoleucas*, brown trout, rainbow trout, channel catfish *Ictaluras punctatus*, fathead minnow, and red shiner *Notropis lutrensis* (Table 6).

Non-native Fishes and Hypotheses of Invasion

Characteristics of Non-native Fishes

Looking at the various characteristics of these species, we found the most widely distributed and abundant non-native fish species ranged widely among each variable we considered. The species ranged morphologically from being large bodied, top predators, to small-bodied herbivores and insectivores. The species have been introduced from all parts of North America, as well as from Asia and Europe. The species ranged physiologically from being tolerant of warm water temperatures to species tolerant of cold mountain streams, and from being highly sensitive to nutrients and measures of water quality, to being highly tolerant to degraded systems. There was also a range in reproductive strategies ranging from vegetative egg layers, to builders of guarded nests, to live bearing species (Table 7)

The only characteristic found to be common among all of the species is that they are all commonly stocked as sport or food fish, or used as forage or bait for sport fish, with the only exception being mosquitofish, stocked for biological control.

Characteristics of Sites With Non-native Species

We did not find non-native fishes, as a group, more likely to be present in more disturbed streams (Table 8**)**. Conversely, I found that non-native fish tended to increase in relative abundance in less disturbed streams, although they also were highly abundant in the most disturbed streams (Correlation, $r = 0.23$, $P < 0.01$) (Table 9 and Figure 3). There was also a notable difference in the type of species found to be most prevalent according to the level of human disturbance (Table 10).

We found that non-native fish, as a group, were distributed throughout the streams influenced by all levels of human disturbance, and across each type of land-use. Streams in forested lands had the lowest likelihood (43.8 $\pm$ 5.5%) of having non-native fishes. This was significantly lower than for rangeland and agricultural areas in which the likelihood of hosting non-native fishes was 64.3% ($\pm$ 7.3) and 67.2% ($\pm$ 12.1), respectively (ANOVA, F = 6.5, $P<0.0001$, Tukey-Kramer HSD). Approximately 60% of stream length flowing through urban areas hosted non-native fish species (58.2 $\pm$ 23.3%), and about 50% of stream length passing through suburbs and towns (47.9 $\pm$ 20.4%) held non-native fish. Estimates for suburban/town and urban landscapes are not presented because sparse data from these regions resulted in low precision (Table 11).

Though forestlands had the lowest proportion of stream length with non-native fish species present, we found that when non-natives were present, they were at the highest levels of relative abundance compared to all other landscapes. Agricultural regions had the greatest proportion of stream length hosting non-native species, but the lowest average relative abundance of non-native fishes. There was also a difference in the type of species found to be most prevalent within each type of land-use (Table 12).

The effect of isolation from humans was unclear. Non-native fishes were more likely to be present in areas that had higher road density (T-test, t = 1.9, P = 0.06), and in areas that had lower human population densities (T-test, t = -1.8, P = 0.07) (Table 8).

Characteristics of Species Assemblages With Non-native Fishes

Non-native fishes were more likely to be in streams that had a greater number of native fish species (T-test, t = 1.6, P <0.01), but less likely to be in streams that had higher densities of native fishes (T-test, t = -9.4, P <0.01). Non-native fishes had lower relative abundance in streams that had a high number of native fish species (Correlation, r = -0.60, P <0.01) and in streams with higher densities of native fish (Correlation, r = -0.27, P <0.01) (Tables 8 and 9).

Non-native fishes were more likely to be found in higher order, larger streams, that generally hosted richer species communities (T-test, t = 6.3, P <0.01). However, non-native fishes were found to be higher levels of relative abundance in lower order, generally smaller, streams (Correlation, r = -0.43, P <0.01) (Tables 10 and 14).

Relative Importance of Non-native Fishes and Landscape Disturbance on Native Fishes

We found native fishes were more likely to be present in more disturbed streams (T-test, t = -3.6, P = <0.01), and also were also found in higher levels of relative abundance at more degraded sites (Correlation, r = -0.07, P <0.01). Native fishes were also more likely to be present in areas that had higher human population densities (T-test, *P* = 0.02, n = 620), though the relative abundance of native fish decreased as road density increased (Correlation, *r* = -0.10, *P* = 0.02) (Tables 8 and 9).

Native fishes were less likely to be present in streams that had higher densities of non-native fishes (T-test, *t* = -9.4, *P* <0.01). Native fishes were likely to be less abundant in streams that had more non-native species in the assemblage (Correlation, *r* = -0.51, *P* <0.01), and in streams that had higher densities of non-native fishes (Correlation, *r* = -0.55, *P* <0.01) (Tables 8 and 9), though not all of the native species may still persist.

We found that 24.4% (SE = 0.01) of stream kilometers that host native species were found to be in highly disturbed regions (levels 1 and 2), while non-native fishes were found in 43.7% (SE = 0.02) of all stream kilometers that host native fishes.

Discussion

Regional Overview

Streams in southwestern states had the greatest representation of non-native fish by percent of non-native species, percent of stream length where they were present, and relative abundance of non-native fishes in the species assemblages. One possible explanation for this pattern is that this area had fewer native fish species historically, and even fewer species that were utilized as food by European settlers, allowing for the greater opportunity or need to introduce non-native species. The southwestern states of Colorado, Nevada, Arizona, and Utah, have the 3rd, 5th, 7th, and 10th highest numbers of fish species respectively introduced in the United States (Fuller et al. 1999). Another explanation for this pattern may be that this arid region has fewer stream kilometers than other regions of the west. Because of this, an equal level of effort of introducing non-native fishes across the landscape would yield a higher proportion of the streams in the Southwest being stocked than in other regions.

The Southwest has a wider climatic gradient than more northern latitudes, ranging from desert to alpine climates with altitude (Strahler and Strahler 1998). This may have allowed for a greater spectrum of fish species to become established than in more northern states that have a more limited thermal range (Fuller et al. 1999). This would also imply that a wider range of species was introduced into the region.

Southwestern states have lost the greatest number of native fish species to extinction, with Nevada having lost seven (Miller et al. 1989). These states have lower diversity of native species, yet a great proportion of endemic species. The need to identify and protect remaining populations of these fishes is crucial in maintaining the unique diversity evolved to live in the myriad of climatic and environmental conditions of the region.

Generalization and Non-native Fishes in the West

It must be kept in mind that any correlations based upon this observational data cannot be assumed to prove causality, and that the variables used to in the analyses, may not appropriately capture variation. There may also be potential problems due to the variation of the scale on which groups of variables were measured, and from residual bias in qualitative measures beyond that controlled by standardization of techniques.

Additionally, factors that may be important at the time of an introduction may be different from the factors found to be important after an introduction occurs.

Characteristics of Western Non-native Species

The most widely distributed and abundant non-native fish species in western streams were sport and food fish, a number of cyprinids introduced from bait releases and as forage, and the mosquitofish introduced for biological control. Though these species tend to have some of the greatest distributions and levels of relative abundance in western streams, I found no obvious similarities or characteristics that would make them more invasive. Any similarities among these non-native fishes were most likely artifacts of humans valuing specific characteristics of species, predominantly for sport and consumption. Because humans know the types of environments to which these fish can be successfully introduced, a select group for a majority of stocking efforts.

Brook trout, brown trout, rainbow trout, largemouth bass, smallmouth bass, and green sunfish have been introduced to western streams since the late 1800's (Rahel 1997). Introduction of these species continued recently, with an estimated 35 million largemouth bass being introduced across the United States over a 4-year period (1966 - 1970). Common carp have been successfully introduced to 49 of the 50 United States, beginning with the introduction of 2.4 million across the country from 1886 – 1896, for commercial fisheries (Nico and Fuller 1999). Mosquitofish have been widely distributed since the 1950's for mosquito control (Fuller et al. 1999).

Because the majority of these most prominent non-native fishes continue to be introduced for sport fisheries, managers need to consider the implications of putting these species into western waters, and what steps will be necessary to eliminate and mitigate their impact on native species (Pascual 2002). Examination and modification of sport fish stocking and management programs would be important for slowing future invasions in western streams. Additionally, further study of all fish introductions (sport, biological control, and conservation efforts) would increase our understanding of how to best manage sport fishes, understand the risk and management of non-intentional introductions, as well as help guide efforts to re-introduce native fish populations, and should be part of all management programs (Moller 1996). Surveys could be implemented both before and after stocking events to study current stocking events, while a compilation of data from all regions for all known stocking events (successful and un-successful) could help us understand the reasons for successful introduction of non-native species in the past (Rosenthal 1980, Nico and Fuller 1999, Gido and Brown 1999).

Characteristics of Western Streams Hosting Non-native Fishes

That presence and abundance of non-native fish was higher in less disturbed streams seems counter-intuitive and contrasts with findings in studies such as Leidy and Fiedlers (1985) in the San Francisco Bay Drainage. However, non-native salmonid species had the greatest distributions and some of the highest levels of relative abundance throughout western streams. These species were also most associated with less disturbed streams.

While non-native fishes, as a group, were present in all types of land-use and levels of human disturbance, patterns emerged when non-natives were examined on a family and species level (Tables 10 and 12). Consistent with findings of Waite and Carpenter (2000) and Hughes et al. (1998), forestlands, which also hosted the most pristine streams, were more likely to host non-native salmonids. Species that are more tolerant of degraded or enriched waters, such as common carp, mosquitofish, centrarchids, and ictalurids were most common in the less pristine reaches of agricultural and urban regions.

We would expect such variation of species among the ecosystem to occur, as species have evolved to be morphologically, physiologically, and behaviorally to be adapted to unique environments. As each species is limited to a specific set of conditions that constitute habitat, the unique distribution of non-native fishes is most evident on a species-specific level. Disturbance does not necessarily create habitat for non-native fishes as a group, but it might create opportunities for specific species.

Similar to other studies (Levine 2000), we found that non-native species were more likely to be present at sites with greater native species richness. Because of unique characteristics of each non-native species and each assemblage of native species, there is most likely a non-native species that would be able to invade a native fish community despite the number of species.

Non-native species Vs. Habitat Degradation

Human alteration and non-native fishes have both impacted a large portion of riparian ecosystems and streams hosting native fishes, and may effectively cause the loss of habitat of native fish species. Human disturbance changes the physical parameters a site that determine the abiotic conditions that help define habitat for native fish species (Wilcove et al. 1998, Williams 1989). The addition of non-native fishes changes the biotic parameters of a site, and through competition or predation, may affect the conditions that define a native species habitat. Both human alteration and introduced species can redefine the bounds of a species habitat and lead to fragmentation, local or regional extinction of native fish populations.

Though the relative influence of both distribution and non-native fishes ultimately depends upon whether a specific species is adapted to persist despite specific changes to the ecosystem caused by disturbance, or an introduced species, we could arrive at some general conclusions about disturbance and non-native species as a group. Non-native fishes were found throughout the landscape despite the level and type of human disturbance, and in a greater proportion of streams (43.7%) than those affected by high levels of human impact (24.4%). While human disturbance was not associated with the presence of native fishes as a group, native fishes were negatively associated with the presence, abundance, and density of non-native fishes. Without undermining the importance of landscape disturbance by humans, we agree with Richter's (1997) conclusion that non-native fishes pose an equivalent, if not greater threat to native fishes than habitat degradation in western streams.

Conclusion

Because each non-native fish species has a unique set of adaptations and tolerances, there will likely be no general rules of invasiveness that will prove useful for prediction in specific cases (Shrader-Freschette 2000). Therefore methods to eradicate and suppress non-native fishes may need to be developed from studies of a specific species. However, the study of non-native fishes as a group may serve as a logical first step in our understanding of the general patterns and relative importance of non-native fishes across the landscape.

The analysis of large-scale sampling may serve its most useful purpose as a warning, implicating the need to educate not only fisheries managers, but the public as well, about the scale and potential problem now posed by non-native fish species in western streams. The streams that are currently free of non-native fishes are most likely those that have yet to have the "right" species introduced (Gido and Brown 1999). Therefore further investigation of the impact of non-native fishes on native species is important across the West. Because the potential harm posed by non-native fishes and methods of controlling them are still largely unpredictable, managing the threat of non-native fishes will be one of the greatest and most important challenges for aquatic managers in the West.

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Table 1. - Variables examined to describe the presence and relative abundance of native and non-native fish species in 12 western states 2000 to 2002.

Variable	Type of variable	Data values	Transformation used
Native species presence	Dummy	0 and 1	None
Non-native species presence	Dummy	0 and 1	None
Native fish density	Continuous	<0.01 – 6.3 fish/m²	Log
Non-native fish density	Continuous	<0.01 – 2.8 fish/m²	Log
Native species relative abundance	Continuous	0 – 100%	Logit
Non-native species relative abundance	Continuous	0 – 100%	Logit
Number of species	Continuous	0 – 25	None
Number of native species	Continuous	0 – 16	Log
Number of non-native species	Continuous	0 - 9	Log
Latitude	Continuous	32.7 – 48.9° N	None
Longitude	Continuous	-124.6 - -96.5° E	None
Stream order (Strahler order)	Categorical	0-8	None
Elevation	Continuous	-8 – 3356 m	Log
Dominant land-use	Categorical or Continuous Dummy	(1) Forest, (2) Range, (3) Agriculture, (4) Suburban (5) Urban	None
Level of human disturbance	Discrete	1 – 5	
Human population density	Continuous	0 – 5824/ km²	Log
Road density	Continuous	0 – 134 km/648 km² grid	Log

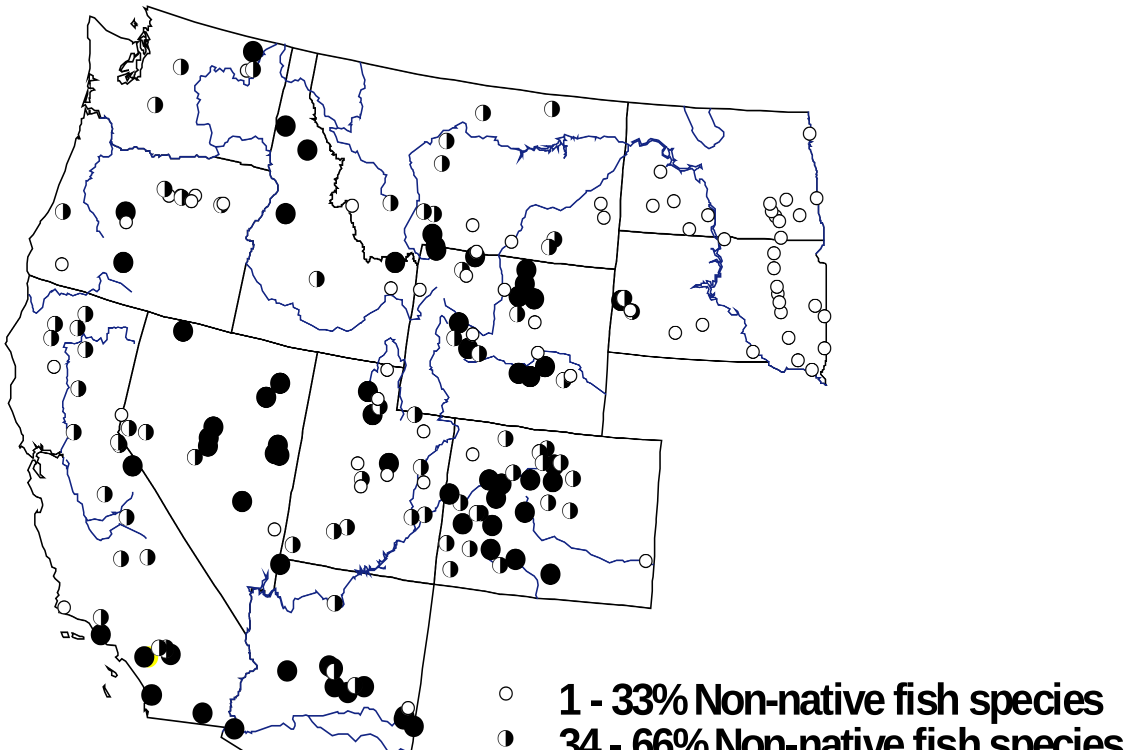

Figure 1. –Proportion of fish assemblages consisting of non-native species (# non-native species/ total # species) for streams in western states 2000 -2002.

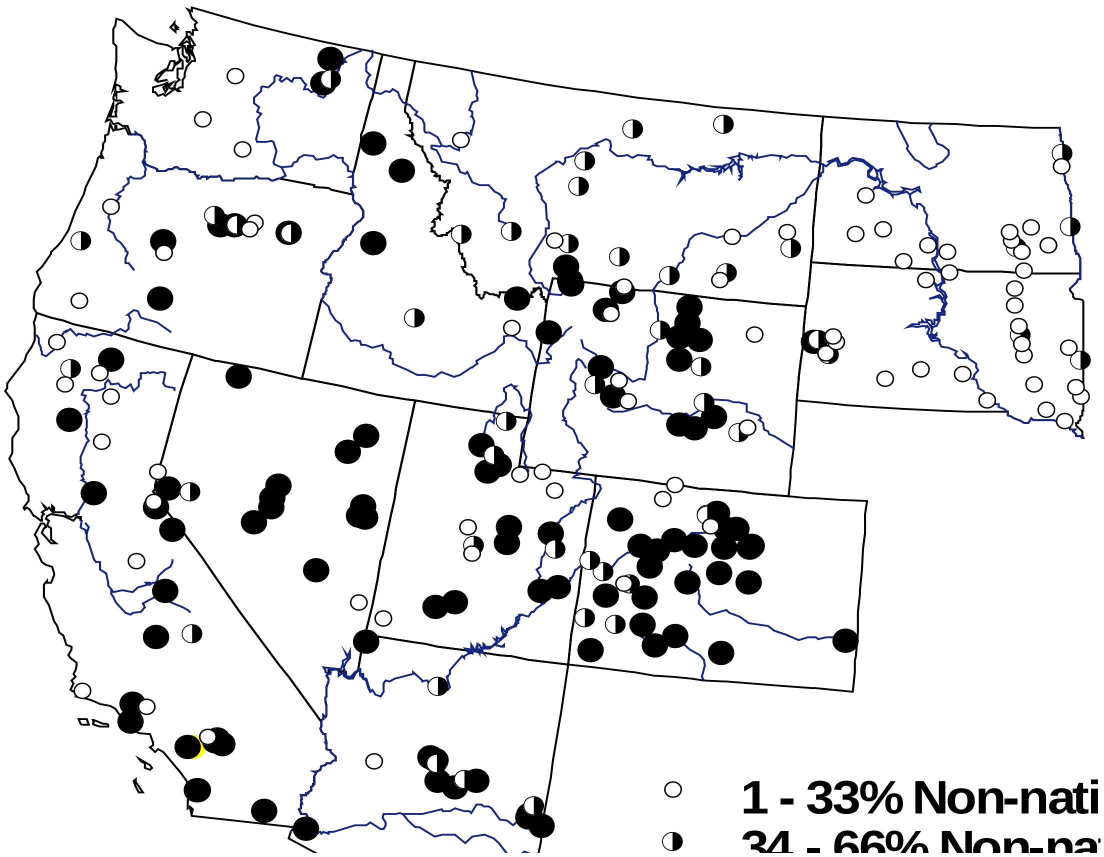

Figure 2. –Proportion of individual fish in a site assemblage consisting of non-native fish (# non-native fish/ total # fish) in streams in western states 2000-2002.

Table 2. –Percent of stream length, and 95% confidence interval, that host non-native fishes, native only assemblages, purely non-native fish assemblages, and no fish, in 12 western states 2000 - 2002.

State	Length with non-native fishes present	Length with only native fishes	Length with only non-native fishes	Length with no fish
Colorado	72.6 ± 13.7	9.4 ± 9.0	29.8 ± 14.0	18.1 ± 11.8
Montana	68.6 ± 20.5	14.1 ± 15.4	3.5 ± 8.1	17.3 ± 16.7
Arizona	66.7 ± 17.0	14.0 ± 12.4	12.9 ± 12.1	19.3 ± 14.2
Utah	65.8 ± 16.5	20.0 ± 13.9	7.2 ± 9.0	14.2 ± 12.2
North Dakota	60.9 ± 15.4	35.6 ± 15.0	-	3.6 ± 5.9
South Dakota	53.1 ± 14.5	44.9 ± 14.4	4.3 ± 5.9	2.0 ± 4.1
Wyoming	47.0 ± 18.0	25.8 ± 14.8	19.6 ± 14.3	27.2 ± 16.0
Nevada	44.1 ± 17.0	37.2 ± 16.6	25.4 ± 14.9	18.7 ± 13.4
California	43.0 ± 15.1	40.0 ± 14.9	3.4 ± 5.5	17.0 ± 7.4
Idaho	25.1 ± 14.7	42.0 ± 16.8	12.0 ± 11.0	32.8 ± 15.9
Oregon	23.8 ± 13.6	60.8 ± 15.6	6.4 ± 7.8	15.4 ± 11.6
Washington	17.7 ± 13.5	48.9 ± 16.7	4.6 ± 7.2	33.4 ± 16.7

Table 3. –Average relative abundance and 95% confidence interval of non-native fish in streams in 12 western states 2000 - 2002.

State	Relative abundance of non-native fish for entire state
Colorado	66.0 ± 10.8
Arizona	50.5 ± 19.0
Wyoming	42.3 ± 12.3
Nevada	40.5 ± 20.3
Utah	38.5 ± 16.0
California	25.6 ± 9.2
Montana	22.9 ± 11.3
Idaho	20.4 ± 10.4
South Dakota	13.3 ± 14.4
Washington	12.3 ± 11.0
Oregon	10.8 ± 8.5
North Dakota	8.2 ± 17.3

Table 4. –Total number, number of non-native, and number of native fish species, and proportion of species that were non-native in 12 western states 2000 - 2002.

State	Total species	Non-native species	Native fish species	Proportion non-native species (%)
Arizona	27	16	11	59.3
Colorado	36	19	25	52.8
North Dakota	23	12	12	52.2
Utah	41	17	24	41.5
California	53	21	31	39.6
Montana	57	18	40	31.6
Wyoming	35	9	29	25.7
Oregon	53	13	40	24.5
South Dakota	73	17	61	23.3
Washington	38	7	31	18.4
Nevada	71	13	62	18.3
Idaho	21	3	19	14.3

Table 5. -Percent of stream length and 95% confidence interval of most widely distributed non-native fish in western streams 2000 - 2002.

Rank	Species	Distribution
1	Brook trout	17.2 ± 3.0
2	Brown trout	15.2 ± 2.8
3	Rainbow trout	11.4 ± 2.5
4	Common carp	9.3 ± 2.3
5	Smallmouth bass	6.2 ± 1.9
6	Largemouth bass	3.0 ± 1.3
7	Green sunfish	2.6 ± 1.2
8	Fathead minnow	2.5 ± 1.2
9	Yellow perch	2.2 ± 1.2
10	Yellow bullhead	2.1 ± 1.1

Table 6. -Average relative abundance and 95% confidence interval of non-native species with the greatest abundance in western streams 2000 - 2002. Only species found in ≥2 sites were considered.

Rank	Species	Relative abundance
1	Brook trout	64.4 ± 5.4
2	Cutthroat trout	51.1 ± 31.0
3	Mosquitofish	47.9 ± 19.8
4	Golden shiner	33.5 ± 22.1
5	Brown trout	29.3 ± 5.7
6	Rainbow trout	19.1 ± 6.5
7	Channel catfish	18.5 ± 26.7
8	Fathead minnow	17.3 ± 14.1
9	Red shiner	15.4 ± 15.7
10	Smallmouth bass	15.0 ± 8.9

Table 7. –Characteristics of non-native species found to be most distributed and abundant throughout the 12 western states in 2000-2002.

Species	Reason for introduction	Trophic level(s)[1]	Adult body size (mm)	Species origin	Reproduction strategy[2]	Water quality tolerance[3]	Thermal minimum temperature	Thermal maximum temperature
Brook trout	Sport	I, Pi, T	200-400	Eastern N.A.	NLN	S		29.8
Brown trout	Sport	I, B, Pi, T	206-826	Europe				30.0
Rainbow trout	Sport	I, T	250-750	Western N.A.	NLN	S	0.16	29.8
Common carp	Food	B, I, H	216-1220	Asia	V	T		
Smallmouth bass	Sport	B, I, Pi, T	200-560	Central/Eastern U.S.	LN	I		36.9
Largemouth bass	Sport	B, I, Pi, T	120-700	Central/Eastern U.S.	PN	T	3.2	40.1
Green sunfish	Sport	B, I, Pi, T	120-250	Central/Eastern U.S.	PN	T		37.9
Fathead minnow	Bait	H, I	43-102	N.A. East of Rockies	P/CN	T	5.9	36.9
Yellow perch	Sport/ forage	P, B, T	152-305	N.A. East of Rockies	V	I		
Yellow bullhead	Sport	B, Pi, T	380	Central/Eastern U.S.	P/CN	T		37.9
Cutthroat trout	Sport	B, I, T	300-485	Rockies	NLN	S		29.9
Mosquitofish	Bio-control	I, Pl, H, Pi	19-59	S and E coast U.S.	LB	T		43.7
Golden shiner	Bait/forage	B, I, H	53-234	Central/Eastern N.A.				36.8
Channel catfish	Sport	Pi, B, I	1270	N.A. East of Rockies			2.7	42.1
Red shiner	Bait	H, Pl, I, B	24-75	Mississippi and Gulf drainages				39.6

Note: Data from McClane 1974, Lee et al. 1980, Hughes et al. 1998, Beitinger et al. 2000

[1] (B)enthivore, (H)erbivore, (I)nsectivore, (Pl)anktivore, (Pi)scivore, (T)op carnivore

[2] LN, lithophil nester, NLN, nonguarding lithophil nester, V, vegetative, PN, psammophil nester, P/CN psammophil cavity nester, LB, live bearer.

[3] (T)olerant, (I)ntermediate, (S)ensitive

Table 8. -Relationships (t-tests) of non-native and native fish presence and biotic, abiotic and human variables 12 western states in 2000 – 2002.

	Non-native present		Native present	
	t	*P*	*t*	*P*
Number of species	7.2	<0.01	6.9	<0.01
Number of native species	1.6	<0.01	-	-
Number of non-native species	-	-	-1.2	0.23
Native fish density	-9.4	<0.01	-	-
Non-native fish density	-	-	-8.2	<0.01
Latitude	-4.3	<0.01	3.4	<0.01
Longitude	9.1	<0.01	-3.1	<0.01
Elevation	6.9	<0.01	-6.8	<0.01
Strahler order	6.3	<0.01	6.4	<0.01
Human population	-1.8	0.07	2.4	0.02
Level of human disturbance	-0.5	0.64	-3.6	<0.01
Road density	1.9	0.06	0.4	0.7

Table 9. - Relationships (correlations) of non-native and native fish relative abundance and biotic, abiotic and human variables in 12 western states 2000 – 2002.

		Native relative abundance	Non-native relative abundance	Native density	Non-native density	Number of species	Number of native species	Number of non-native species	Latitude	Longitude	Elevation	Stream order	Population	Road density	Level of human disturbance
Native fish relative	*r*	1	-.99	.41	-.55	-.01	.18	-.51	.23	-.29	-.35	-.02	.09	-.05	-.07
abundance	*P*	.	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Non-native fish	*r*	-.99	1	-.27	.57	-.57	-.60	-.22	-.25	-.01	.34	-.43	-.07	-.04	.23
relative abundance	*P*	.00	.	.00	.00	.00	.00	.00	.00	.07	.00	.00	.00	.00	.00
Native fish density	*r*	.41	-.27	1	.71	-.42	-.32	-.45	-.13	-.06	.05	-.43	-.11	-.04	.19
	P	.00	.00	.	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Non-native fish	*r*	-.55	.57	.71	1	-.60	-.61	-.29	-.38	.07	.39	-.53	-.14	.02	.26
density	*P*	.00	.00	.00	.	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Number of fish	*r*	-.01	-.57	-.42	-.60	1	.95	.54	.18	.24	-.30	.47	.11	.17	-.34
species	*P*	.00	.00	.00	.00	.	.00	.00	.00	.00	.00	.00	.00	.00	.00
Number of native	*r*	.18	-.60	-.32	-.61	.95	1	.26	.26	.18	-.39	.41	.12	.16	-.32
species	*P*	.00	.00	.00	.00	.00	.	.00	.00	.00	.00	.00	.00	.00	.00
Number of non-native	*r*	-.51	-.22	-.45	-.29	.54	.26	1	-.17	.27	.11	.34	.01	.09	-.18
fish species	*P*	.00	.00	.00	.00	.00	.00	.	.00	.00	.00	.00	.00	.00	.00
Latitude	*r*	.23	-.25	-.13	-.38	.18	.26	-.17	1	-.06	-.37	.00	-.08	-.09	-.01
	P	.00	.00	.00	.00	.00	.00	.00	.	.00	.00	.10	.00	.00	.00
Longitude	*r*	-.29	-.01	-.06	.07	.24	.18	.27	-.06	1	.34	.34	-.31	-.07	.05
	P	.00	.07	.00	.00	.00	.00	.00	.00	.	.00	.00	.00	.00	.00
Elevation	*r*	-.35	.34	.05	.39	-.30	-.39	.11	-.37	.34	1	-.10	-.30	-.31	.40
	P	.00	.00	.00	.00	.00	.00	.00	.00	.00	.	.00	.00	.00	.00
Stream order	*r*	-.02	-.43	-.43	-.53	.47	.41	.34	.00	.34	-.10	1	-.04	.03	-.20
	P	.00	.00	.00	.00	.00	.00	.00	.10	.00	.00	.	.00	.00	.00
Population	*r*	.09	-.07	-.11	-.14	.11	.12	.01	-.08	-.31	-.30	-.04	1	.25	-.18
	P	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.	.00	.00
Road density	*r*	-.05	-.04	-.04	.02	.17	.16	.09	-.09	-.07	-.31	.03	.25	1	-.30
	P	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.	.00
Level of human	*r*	-.07	.23	.19	.26	-.34	-.32	-.18	-.01	.05	.40	-.20	-.18	-.30	1
disturbance	*P*	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.

Figure 3. –Mean relative abundance of non-native fish species according to level of human disturbance in 12 western states 2000 - 2002.

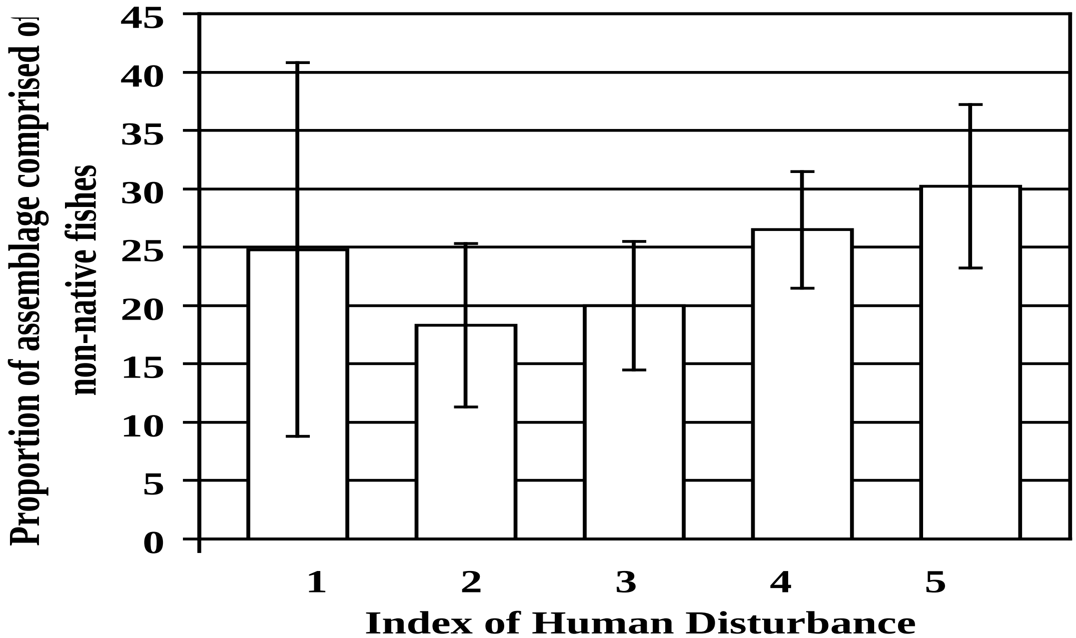

Table 10. –Distribution (percent of km) and 95% confidence interval of the most widely distributed non-native fish species in each level of disturbance in 12 western states 2000 - 2002.

Level of disturbance	Most common species	Distribution
1	Common carp	16.5 ± 15.5
	Mosquitofish	15.4 ± 15.1
2	Common carp	20.1 ± 10.1
	Largemouth bass	12.3 ± 8.3
3	Brown trout	16.4 ± 7.6
	Rainbow trout	14.2 ± 7.2
4	Brook trout	19.3 ± 7.9
	Brown trout	14.7 ± 7.0
5	Brook trout	21.8 ± 13.7
	Brown trout	7.6 ± 8.3

Table 11. - Percent and 95% confidence interval of stream length that host native and non-native fishes, average relative abundance of non-native fishes, proportion of total stream length, and average level of human disturbance by land use in 12 western states 2000 - 2002 .

	Streams with non-native fishes	Streams with native fishes	Relative abundance of non-native fishes	Proportion of total stream length	Level of disturbance
Agriculture	67.2 ± 12.1	94.0 ± 8.0	19.0 ± 9.1	9.1 ± 2.3	2.6 ± 0.2
Range	64.3 ± 7.3	89.8 ± 4.8	23.9 ± 2.4	27.0 ± 3.4	3.2 ± 0.1
Urban	58.2 ± 23.3	100.0 ± 22.1	25.6 ± 25.0	1.2 ± 0.8	2.7 ± 0.7
Suburban/ Town	47.9 ± 20.4	99.5 ± 13.5	21.3 ± 15.6	3.5 ± 1.4	2.6 ± 0.4
Forest	43.8 ± 5.5	84.4 ± 3.6	26.1 ± 4.1	59.2 ± 3.8	4.0 ± 0.1
All Sites	50.1 ± 3.9	87.9 ± 1.3			3.6 ± 0.1

Table 12. - Distribution (percent of km) and 95% confidence interval of the most widely distributed non-native fish species by land use in 12 western states 2000 - 2002.

	Most common species	Distribution
Forest	Brook trout	19.4 ± 8.0
	Brown trout	10.3 ± 5.0
Range	Brown trout	19.7 ± 7.0
	Rainbow trout	19.0 ± 6.9
Agriculture	Common carp	28.6 ± 10.5
	Brown trout	15.9 ± 9.2
Suburban/town	Smallmouth bass	13.9 ± 17.5
	Black bullhead	12.3 ± 16.6
Urban	Golden shiner	26.2 ± 38.5
	Largemouth bass	26.2 ± 38.5

CHAPTER 2

Factors associated with the presence and abundance of 10 selected non-native fish species in the American West

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Abstract- Non-native fish species have been implicated in native fish extinction and endangerment in the United States. It is important that the unique history, success and impact of specific species becoming naturalized in new environments be studied to help control further distribution of these species. We studied 10 non-native fish species, selected for their impact on native fishes and their distribution in the American West. Access to data from a standardized sample of streams across the American West allowed study of factors affecting distribution and abundance of these species at a scale that has rarely been approached, and develop quantitative means to predict successful invasions. Each species had a unique pattern of distribution and abundance in relation to the biotic, abiotic, and human variables across the landscape. We present three complementary methods to predict the success and extent of invasion for specific species, to help in designing and implementing the best management strategies for these non-native fishes across western states.

Introduction

Non-native fish species (i.e., those found outside their indigenous range) contributed to 63 % of native fish extinctions in the past 100 years, and have been implicated in 49% of endangered species listings in the United States (Miller et al. 1989, Lassuy 1995, Magnusson et al. 1998, Wilcove et al. 1998, Mack et al. 2000, Shrader-Frechette 2001). Non-native fish have had a profound impact on the structure and function of ecosystems, and through predation, competition, and hybridization with native species, have contributed to the decline of biological diversity of American stream fauna (Deacon 1988, Miller et al. 1989, Hughes and Noss 1992, Allen and Flecker 1993, Vitousek et al. 1997, Whittier et al. 1997, D'Antonio and Haubensak 1998, Allen et al. 1999, Waite and Carpenter 2000, Shrader-Frechette 2001).

By 1999, 536 non-native fish species from 75 families, and 6 continents had been introduced in inland waters of the United States (Nico and Fuller 1999). These fishes have evolved morphologies, behaviors and physiologies to be successful in a wide spectrum of ecological niches, and are now found across all types of land-use, over the entire range of human disturbance, and in every drainage basin across the United States (Schade 2004, Fuller et al. 1999, Gerking 1994).

Since the end of the 19^{th} century, streams of the western United States have been the focus of species introduction efforts. Many western states now have a greater diversity of non-native fishes than native fishes in stream communities (Fuller et al. 1999, Nico and Fuller 1999, Schade 2004). Many species continue to be introduced for sport fishing, as bait fish, from aquarium releases, and for biological control.

Though some studies have tried to identify underlying processes of invasion (Ross 1991, Lassuy 1995, Arthington et al. 1983, Leidy and Fiedler 1985, Schlosser 1991, Ross et al. 2001, Castleberry and Cech 1986, Moyle and Light 1996, Waite and Carpenter 2000), there are likely no general rules or laws that explain successful invasion. The outcome of fish introductions is based upon characteristics of individual species and the site into which it is introduced (Schrader-Frechette and McCoy 1994, Moyle and Light 1996, Schrader-Freschette 2001). To determine if a particular non-native fish can successfully invade an area, or to assess its potential impact on existing fauna and flora, it is important to study the unique history and success of species becoming naturalized in new environments, and the parameters and features of an area that allow successful invasion by that species (Whittier et al. 1997, Parker et al. 1999, Whittier and Kincaid 1999, Pascual et al. 2002 Brown 1989, Mack et al. 2000).

Few studies have examined species introductions in a landscape larger than a watershed, or have pooled data from many sources to patch together a larger region for analysis (Moyle and Light 1996, Gido and Brown 1999). Large-scale studies of aquatic environments, such as the National Water Quality Assessment (NAWQA) program and Environmental Monitoring and Assessment Program (EMAP) - Surface Waters, have begun recently (USGS 2003, Peck et al. 2002), and have provided standardized data from across the American West. This allowed the opportunity to study the factors associated with distribution and abundance of specific non-native fish species at a large, regional scale.

Our first objective was to quantitatively describe major patterns in the distribution and relative abundance of 10 non-native fish species in the American West. These species were selected based upon their known impact on native fishes, and the extent of their distributions. We examined how the presence of particular non-native fishes was related to species abundance and diversity in the local assemblages. Our second objective was to identify which biotic, abiotic, and anthropogenic factors were most closely related to the presence and relative abundance of each selected non-native fish species. Such information will help managers understand the patterns of diversity of native and non-native fish, predict where these species might invade, and predict where they might become abundant.

Methods

Data on the presence and abundance of over 180 fish species and hybrids, and various characteristics of riparian systems in which they were found, were collected from 689 sites during a 3-year (2000-2002) survey across 12 western states (Arizona, California, Colorado, Idaho, Montana, Nevada, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming) (Table 1). Data were collected as part of the U.S. Environmental Protection Agency (EPA) Western Pilot Study of the EMAP-Surface Waters program designed to monitor and assess trends, stressors, and status of ecological conditions of flowing waters (Peck et al. 2001). All sampling crews were trained by EPA personnel in field measures and protocol, and were issued equivalent gear to ensure standardization of all measures.

Sample sites were chosen by a stratified random selection from all reaches of perennial stream identified on 1:100,000 scale USGS maps, excluding the main stems of the Colorado, Columbia, Snake and Missouri rivers. The sample population was weighted such that sites within each strata represented the size of the strata, resulting in estimates that represent conditions for all western streams (>650,000 km).

The reach of stream surveyed at each site was equal to 40 times the channel width, with a minimum length of 150 m. The landscape surrounding each sampling site was categorized by dominant land use and level of human disturbance. The land-use categories were, forest, range, agriculture, suburban/town, and urban. Level of human disturbance was based upon a scale of 1 (totally developed) to 5 (pristine). This determination was a visual assessment of the degree of impact to stream morphology, riparian structure, and water quality, due to human activity.

Physical parameters collected for each site included stream order, channel width and depth (to calculate volume and cross-sectional area), mean stream gradient (using a clinometer), mean substrate size (categorical classification of randomly selected particles), dominant channel type (percent rapid or riffle, and percent glide or pool), mean percent instream fish cover (visual estimate of the amount of filamentous algae, macrophytes, or other cover), and mean percent canopy cover (using a spherical densiometer).

Crews used a backpack electrofishing unit to perform a single upstream pass (total shocking time = 45 to 180 min.) through a reach to sample fish. Species and numbers of individuals were recorded for each site. The Smithsonian Institution was provided voucher samples of species collected in the field to verify field identification (Peck et al. 2001).

Relative abundance of species for each site was estimated by dividing the number of fish in each species captured by the total number of fish captured. Relative abundance was used as a measure of the predominance of non-native fish in a fish assemblage at each site, because it factors in variation among sites that may affect other measures of fish abundance in an area, such as fish density.

Fish origin (native or non-native) was determined for each species by reviewing 13 sources that included information on species range and history in western states (Churchill and Over 1938, Simon 1951, Bailey and Allum 1962, McClane 1974, Wydoski and Whitney 1979, Lee et al. 1980, Simpson and Wallace 1982, Page et al. 1991, La Rivers 1994, North Dakota Game and Fish 1994, Holton and Johnson 1996, Sigler and Sigler 1996, Nico and Fuller 1999, Moyle 2002). Native fish were defined as those species that naturally occurred at a site. Non-native fish were defined as a species that was at a site outside of its native range. Native and non-native origin was determined to the smallest scale possible (stream, drainage basin, or region).

Species not identified in the field, and awaiting identification by the Smithsonian Institution, were recorded from 102 sites. If the family was known, and was a family with other congenerics known to be native to the drainage or region, the fish was classified as native. If the family was not likely to be native to a drainage or region, the species was classified as non-native. All fish of unknown species and family (found at 6 sites) were classified as native to give a conservative estimate of the presence of non-native fishes in an assemblage.

We used a geographic information system (GIS) to gather data on variables not obtained from the field. Layers of data were imported from various sources and matched to EMAP sites. Average daily temperature change, mean daily January minimum temperature, mean daily July maximum temperature, and mean annual precipitation were based upon 30-year averages (1961 – 1990) from 4,775 temperature stations and 6,662 precipitation stations monitored by the National Oceanic and Atmospheric Administration (NOAA) and compiled by the National Climate Data Center (NCDC 2003). To estimate mean road density and average elevation we used the data associated with surrounding area, based upon a national coverage of a grid of 648 km^2 hexagons developed by the EPA, in which each sample was taken (White et al. 1999). To estimate human density we used the average for the county, based upon the 1995 U.S. Census Bureau survey, from which each sample was taken (USGS 2002).

The human related variables (population density, level of human disturbance, road density, and dominant land-use) were chosen to capture variation in the level and type of human impact to the ecosystem, the potential base of humans that may desire the presence of specific species, and the ease of introducing or transplanting fish species. The physical parameters (stream velocity, gradient, stream order, substrate size, cover, temperature, precipitation) were chosen to capture the structural and spatial variation in the physical world to which a species must be physiologically adapted. The biotic variables (fish density, species diversity) were chosen to capture variation in biotic pressures from other species that fish must tolerate to persist in an area.

Ten fish species were chosen based upon their negative impact on native fishes, and the extent of their distribution in the United States (Table 2). Black bullhead *Ameiurus melas*, channel catfish *Ictaluras punctatus*, green sunfish *Lepomis cyanellus*, largemouth bass *Micropterus salmoides,* brown trout *Salmo trutta*, were selected because these species were most commonly associated with the decline of native fishes in ESA listings (Lassuy 1995), and because they are widely distributed across the American West. Mosquitofish *Gambusia affinis* were chosen because they are one of the most widely introduced fish species for biological control, and have been described as the largest threat to native species in the southwestern United States (Dill and Cordone 1991). Red shiner *Notropis lutrensis* were chosen because they were described as the second largest threat to native fish in the Southwest, and they were cited in ESA listings as contributing to decline of endangered fish (Dill and Cordone 1991, Lassuy 1995). Common carp *Cyprinus carpio* were chosen because they were one of the first fish species to be introduced across the United States by the U.S. Fish Commission; they occurred as non-native in the greatest number of sampling sites in the western EMAP study (97 sites), and they were introduced to 49 states and have naturalized populations in all 12 of the states in the EMAP study (Nico and Fuller 1999). Rainbow trout *Oncorhynchus ourkiss* were chosen because they were the most commonly encountered species outside of its native range during EMAP sampling. They also have been introduced to 48 states, including all 12 of the study states. Fathead minnow *Pimephales promelas* were chosen because they were mentioned in the ESA listing of endangered species; have been introduced in 35 states, and 10 of western states.

We described the general distribution and abundance of these species across the West. Then we examined the relationship between the 10 selected species and the average native and non-native diversity of the fish assemblages in which they are found. We used t-tests and correlations to determine the relationship between the human, biotic and abiotic variables of streams that have become inhabited each species, and in streams where these species have become abundant.

To develop models describing which factors were best related to the presence/absence of each of the 10 fishes, we used step-wise logistic regression procedure. Variables were added until the log-likelihood ratio decreased by <0.10, or until the addition of a term made any portion of the model terms insignificant. Because data were not complete for all variables at each site that had fish, we used data from the set of sites that had complete information to develop these models. The selected model was then run using logistic regression procedure with the entire set of sites that was complete in the variables chosen. This maximized the variation in the greatest number of terms to develop the model, and maximized the variation in the greatest number of sites to test the model.

To develop models describing which factors were best related to relative abundance of each of the 10 fishes, we used step-wise linear regression. The variables were then added until the addition of another term did not decrease Akaike's information criteria (AIC) value (a measure to maximize variation explained, while minimizing terms in the model), or until the addition of a term made any portion of the model insignificant at $\alpha =$

0.05 level. The selected model was then run using linear regression procedure, with the entire set of sites that was complete in the variables chosen. This maximized variation in the greatest number of terms to develop the model, and maximized variation in the greatest number of sites to test the model. There were not enough cases ($\geq$ 6 for each variable) to appropriately develop and properly test the models for the relative abundance of largemouth bass, and red shiner, so no models were presented for these species.

For all variables, distributions and residuals were checked for outliers and shape, and transformations were made to meet the assumptions of linear and logistic regression (Table 1). For the development of each model, variables were screened for correlations before they were entered to the pool, and screened for collinearity as the model was developed. We cross-validated each model to asses its predictive capabilities using jack-knife methods.

Results

Summary of species distribution

The 689 sample sites represent over 650,000 km of stream reaches. The 10 species ranged from being predominantly native across the region, such as channel catfish and black bullhead that were transplanted within the region, to entirely non-native, such as mosquitofish that were introduced from streams near the Gulf of Mexico and south-eastern coast, and brown trout and common carp that were introduced from Europe (Figure 1 and Table 3).

Brown trout had the greatest distribution of non-native species, being present in about 15% of the length of western streams. Rainbow trout and common carp were non-native in about 10% (Table 4). These three species along with largemouth bass, green sunfish, and fathead minnow were in the top 10 most widely distributed non-native fish species across the American West (Schade 2004).

Mosquitofish and brown trout had the greatest average relative abundance when present, with mosquitofish comprising about 47.9% (± 19.8) of all individual fish in an assemblage, and brown trout 29.3% (± 5.7) (Table 5). Green sunfish, common carp, black bullhead and largemouth bass were in the top 50% of non-native species by average relative abundance (Schade 2004).

The average number of species at each site was 4.7 (± 0.3, 95% Confidence Interval), with about 1 in 5 species being a non-native. Each of the 10 non-native species chosen was associated with a higher than average total number of fish species, a higher than average number of native species, and a higher than average number of non-native species. Mosquitofish were the only species associated with below average native species diversity (3.3, 95% C.I. = 2.9). Largemouth bass were associated with the highest overall species diversity (13.0, 95% C.I. = 1.8), and the highest native species diversity (9.0, 95% C.I. = 1.5). Channel catfish were associated with the highest levels of non-native species diversity (7.1, 95% C.I. = 1.4) (Table 6).

Species/variable relations and models

For each of the 10 species we measured the ranges and averages for each of the variables at sites it was found (Table 7). We also defined the relationships of the presence and relative abundance of the 10 species with each variable using correlations and t-tests (Tables 8 and 9). We developed models of the most important factors in explaining the presence and relative abundance for each species (Tables 10 and 11). The models can be useful in two ways. They can be used to predict the presence or absence of each species at a site, and of more interest, predict specifically if a species is present. The most significant and consistent findings are reported in the following species profiles.

Species profiles

Black bullhead were most widely distributed in suburban/town and agricultural landscapes (Table 12). The terms that explained the most variation in presence and relative abundance for black bullhead show the species to be associated with lower order, and more open streams, with slow moving water. These streams are most commonly found in less disturbed regions with greater human population densities and warmer temperatures (Tables 7,8, 9, 10, and 11).

Brown trout were most widely distributed in rangeland and agricultural landscapes (Table 12). The terms that explained the most variation in presence and relative abundance for brown trout show the species to be most associated with lower order and faster moving streams. These streams are most commonly found in less disturbed areas and cooler regions (Tables 7,8, 9, 10, and 11). Brown trout have some of the greatest ranges in parameters measured showing they can be found in a wider spectrum of stream morphology (Table 7).

Channel catfish were most widely distributed in rangeland and forested landscapes (Table 12). The terms that explained the most variation in presence and relative abundance for channel catfish show the species to be most associated with higher order streams with slower waters. These streams are most commonly found in regions with warmer temperatures and low levels of precipitation (Tables 7,8, 9, 10, and 11).

Common carp were most widely distributed in agricultural and range landscapes (Table 6). The terms that explained the most variation in presence and relative abundance for common carp show the species to be most associated with higher order, and more open streams with slower moving water. These streams are most commonly found in regions with warmer temperatures (Tables 7,8, 9, 10, and 11).

Fathead minnow were most widely distributed in rangeland and suburban/town landscapes (Table 12). The terms that explained the most variation in presence and relative abundance for fathead minnow show the species to be most associated with larger, slower moving streams. These streams are most commonly found in regions with warmer winter and cooler summer temperatures that have greater daily fluctuation, and in more disturbed sites near greater human population densities (Tables 7,8, 9, 10, and 11).

Green sunfish were most widely distributed in urban and suburban/town landscapes (Table 12). The terms that explained the most variation in presence and relative abundance for green sunfish show the species to be most associated with larger, more open streams with slower moving water. These streams are most commonly found in regions with warmer temperatures with greater daily fluctuation (Tables 7,8, 9, 10, and 11).

Largemouth bass were most widely distributed in urban and agricultural landscapes (Table 12). The terms that explained the most variation in presence and relative abundance for largemouth bass show the species to be most associated with faster moving streams. These streams are most commonly found in regions with warmer temperatures, more affected by human population and disturbance (Tables 7,8, 9, 10, and 11).

Mosquitofish were most widely distributed in urban and agricultural landscapes (Table 12). The terms that explained the most variation in presence and relative abundance for mosquitofish show the species to be most associated with slower moving streams with high levels of instream cover. These streams are most commonly found in regions with warmer winter and summer temperatures, and highly disturbed areas near dense human populations (Tables 7,8, 9, 10, and 11).

Rainbow trout were most widely distributed in rangeland and agricultural landscapes (Table 12). The terms that explained the most variation in presence and relative abundance for rainbow trout show the species to be most associated with low order, high gradient streams with faster moving waters. These streams are most commonly found in regions with cooler temperatures and high annual precipitation (Tables 7,8, 9, 10, and 11).

Red shiner were most widely distributed in rangeland and agricultural landscapes (Table 12). The terms that explained the most variation in presence and relative abundance red shiner show the species to be most associated with higher order streams with faster moving water. These streams are most commonly found in regions with warmer winter and summer temperatures (Tables 7,8, 9, 10, and 11).

Discussion

The most widely distributed non-native fish species in western streams were those most commonly introduced as sport fish (Schade 2004). These species include a number of salmonids, including brown trout and rainbow trout, centrarchids, such as largemouth bass and green sunfish, and cyprinids, including common carp. All of these species have been introduced across the West since the late 1800’s (Rahel 1997). Other cyprinids, including fathead minnow and red shiner, were commonly introduced as bait and forage, while mosquitofish, a small poeciliid, were widely distributed since the 1950’s for mosquito control (Rahel 1997, Fuller et al. 1999).

The distribution of non-native fish species today is a result of two main factors. The first factor is the limitations of each species to the set of stream characteristics to which it is physiologically tolerant, and that provide habitat. The second factor is the extent to which each species has been introduced across the region. We found that human variables might better explain the distribution of these species than their relative abundance (Tables 10 and 11). Relative abundance may be more related to the biotic and abiotic conditions of the areas in which they have been successfully introduced.

Brown trout and rainbow trout were associated with lower order, higher gradient streams with larger substrates, found in regions of forest or rangeland, with cooler temperatures. Such conditions are typical of streams inhabited by native salmonids, and reflect the widespread distribution of non-native salmonids in higher elevation streams in the Rocky Mountains, into which they were most often stocked (Figure 1 and Table 11). Non-native salmonids are probably limited to such streams, as their sensitivity to eutrophic conditions and lower heat tolerance might preclude them from surviving in the conditions and temperatures found more commonly in other land-uses (Tables 7 and 12) (Hughes et al. 1998). The fact that salmonids were the most relatively abundant species may be explained by their increased likelihood of being introduced into fishless streams, or through predation and/or competition they have reduced the abundance of the other species. Both also may account for these species being associated with lower levels of species diversity (Table 6).

Largemouth bass and green sunfish were associated with larger streams with slow moving water, found in more populated regions with warmer temperatures. Such conditions might best mimic the type of streams in which they evolved. Centrarchids typically have a lower tolerance to cold and higher tolerance of more nutrient enriched systems associated with agricultural streams and urban streams that receive effluent (Tables 8, 10, and 12) (Hughes et al. 1998). We found that centrarchids usually occurred in lower relative abundances than salmonids and other species (Table 5). Though, like the salmonids, they are top predators, and were associated with streams that have greater species diversity. They may be more limited by competition and predation by other species within the biotic community than many salmonid populations that live in streams containing few or no other species (Table 5) (Hughes et al. 1998).

Common carp, fathead minnow, red shiner, and mosquitofish were most associated with larger, more open streams with slow moving water, found in more densely populated and disturbed regions. We found cyprinids and mosquitofish most highly associated with warmer January and July temperatures, and most likely limited in their distribution by cold temperatures (Tables 4, 7 and 8) (Fuller et al. 1999). Mosquitofish are most associated with more urban areas, as would be expected for a species introduced for the biological control of mosquitoes around populated areas (Table 12). Cyprinids and mosquitofish constituted some of the largest proportions of the relative abundance in assemblages we studied (Table 5). Most of these species are small, highly fecund, and tend to form large dense schools.

Management implications

Public interest and, more commonly, the Endangered Species Act require mangers to protect and recover species of native fish. Non-native fishes have been shown to negatively impact native species, have been cited as threats to the recovery of native species, and must be considered in the plans for recovery and management.

The information presented in this study will help identify sites that may be susceptible to certain fish species becoming established and developing high relative abundance, and can help identify variables that might be manipulated to favor native fish species over specific non-native species. Managers can choose to do this in three ways.

First, the means and ranges of stream parameters measured and the presence of each species (Table 7) would describe optimal and limits of conditions to which a species may be adapted. This information could be used to help manipulate certain stream conditions to levels that make the stream less inhabitable for non-native species, while remaining within the ranges of native species, such that they would be favored.

Second, the results from individual parameter t-tests could be used to help evaluate the factors related to the potential for a species to become established (Table 8). Correlations can be used to help predict the relative abundance that a species may attain following introduction (Table 9). Such information would also be useful in determining a set of stream parameters that could be manipulated to help manage in favor of native species.

Third, though the ability of the models to predict was poor, managers could use the models of variables most associated with the presence and relative abundance of each species, to help estimate the outcome of a species introduction (Tables 10 and 11). Managers need to collect data for each significant variable, make appropriate transformations, and use these values in the equations (Peck et al. 2002). The result would be a probability of a species presence at a site, and a percent relative abundance of the species within the assemblage, though this may not be directly transferable to predicting the outcome of an introduction.

There are many sources of error for these models. There was sparse data collected on some specific species, given the variation found across wide geographic range in which they were found. There were also potential problems with using data with greatly unequal number of cases of presence and absence of each species. Few models were found to have significant potential to predict the presence or abundance of these species, and the models may be most useful in their descriptive value.

The information the models provide should be used in association with other information or variables that may be more locally relevant (Tables 7, 8, and 9), and with information of the thresholds of native species within a region, or management area. Using the collective data should allow managers to better estimate the potential outcome and impact of a species introduction, and aid in the development of the best management for introduced fish species in the West.

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Table 1. –Variables examined to describe the presence and relative abundance of 10 non-native fish species in 12 western states 2000 to 2002.

Variable	Type of variable	Data values	Transformation used
Species presence/absence (for 10 selected non-native sp.)	Dummy	0 and 1	None
Species relative abundance (for 10 selected non-native sp.)	Continuous	0.1 – 100%	Logit
Stream velocity (flow meter)	Continuous	0.0 –7.2 m/s	Log
Mean gradient (clinometer)	Continuous	0 – 90°	Log
Stream size – Strahler order	Categorical	0-8	Log
Stream size- mean cross-sectional area	Continuous	.01-24.8 m^2	Log
Cover- instream	Continuous	0 – 100%	Logit
Cover- canopy	Continuous	0 – 96%	Logit
Mean substrate size	Categorical	<0.06 mm - bedrock	Log
Percent of reach that is rapid or riffle	Continuous	0 – 100%	Logit
Percent of reach that is glide or pool	Continuous	0 – 100%	Logit
Average January daily minimum air temperature	Continuous	-12.2 – 0.6˚ C	Log
Average July daily maximum air temperature	Continuous	12.8 - >37.8˚ C	Log
Average daily air temperature change	Continuous	-17.8 – 7.2˚ C	Log
Average annual precipitation	Continuous	12.7 – 329 cm	Log
Dominant land-use	Categorical	(1) Forest, (2) Range, (3) Agriculture, (4) Sub-urban (5) Urban	None
Level of human disturbance	Discrete	1 – 5	None
Human population density	Continuous	0 – 5824/ km^2	Log
Road density	Continuous	0 – 134 km/648 km^2 grid	Log

Table 2: Criteria for selecting 10 non-native fish species for analyses of distribution and relative abundance in 12 western sates 2000 - 2002.

	Number of sites detected	Number of sites detected where non-native	Number of United States with introduced populations (Fuller et al. 1999)	Number of 12 western states with introduced populations (Fuller et al. 1999)	Number of citations in ESA listings (Lassuy 1995)	Other citations (Minckley 1973, Dill and Cordone 1991)
Black Bullhead	61	7	21	9	11*	
Brown Trout	76	76	47	12	7	
Channel Catfish	59	7	30	9	7	
Common Carp	97	97	49	12	-	Cited with increasing turbidity and egg predation
Fathead Minnow	95	17	35	10	Cited **	
Green Sunfish	56	26	31	12	9	
Largemouth Bass	18	18	43	12	21	
Mosquito-fish	19	19	37	10	7 ***	Cited with disappearance and reduction of native fish in SW
Rainbow Trout	257	48	48	11	-	
Red Shiner	49	20	12	6	Cited **	Cited with disappearance and reduction of native fish in SW

* 7 citations for bullhead species as a whole

** No number of citations reported

*** There were 7 citations of unnamed pest control species that likely include mosquitofish

Table 3. -Percent of total range of each species and 95% confidence interval of the in which it was non-native in streams in 12 western states 2000 - 2002.

Fish Species	Range
Channel Catfish	12.5 (± 8.6)
Black Bullhead	22.4 (± 10.8)
Rainbow Trout	25.5 (± 5.4)
Fathead Minnow	30.5 (± 9.6)
Red Shiner	49.5 (± 14.5)
Green Sunfish	52.7 (± 13.5)
Brown Trout	100
Common Carp	100
Largemouth Bass	100
Mosquitofish	100

Table 4. –Percent of total stream km and 95% confidence interval in which 10 selected non-native fish species are distributed in streams in 12 western states 2000 - 2002.

Species	Distribution
Brown trout	15.2 ± 2.8
Rainbow trout	11.4 ± 2.5
Common carp	9.3 ± 2.3
Largemouth bass	3.0 ± 1.3
Green sunfish	2.6 ± 1.2
Fathead minnow	2.5 ± 1.2
Red shiner	2.0 ± 1.1
Mosquitofish	1.3 ± 0.9
Black bullhead	1.0 ± 0.8
Channel catfish	0.7 ± 0.6

Table 5. -Average relative abundance (% of individual fish in species assemblage) of 10 selected non-native fish species in 12 western states 2000 - 2002.

Species	Relative abundance
Mosquitofish	47.9 ± 19.8
Brown trout	29.3 ± 5.7
Rainbow trout	19.1 ± 6.5
Channel catfish	18.5 ± 26.7
Fathead minnow	17.3 ± 14.1
Red shiner	15.4 ± 15.7
Green sunfish	11.3 ± 13.9
Common carp	10.8 ± 7.3
Black bullhead	9.1 ± 22.1
Largemouth bass	2.2 ± 12.8

Table 6. -Average total, native, and non-native species richness and 95% confidence interval at sites where an individual species is non-native in 12 western states 2000 – 2002.

Fish Species (common name)	Average number of species in assemblage	Average number of native species in assemblage	Average number of non-native species in assemblage
All fish	4.7 ± 0.3	3.8 ± 0.3	0.9 ± 0.1
Black Bullhead	8.0 ± 3.1	5.3 ± 2.6	2.7 ± 1.2
Brown Trout	5.5 ± 0.7	3.9 ± 0.7	2.1 ± 0.3
Channel Catfish	11.3 ± 3.7	4.3 ± 3.1	7.1 ± 1.4
Common Carp	11.1 ± 1.0	8.0 ± 0.9	3.2 ± 0.4
Fathead Minnow	8.6 ± 2.0	4.0 ± 1.6	4.6 ± 0.7
Green Sunfish	10.0 ± 1.9	5.8 ± 1.6	4.3 ± 0.8
Largemouth Bass	13.0 ± 1.8	9.0 ± 1.5	4.1 ± 0.7
Mosquitofish	5.3 ± 2.8	3.3 ± 2.9	3.2 ± 1.0
Rainbow Trout	6.6 ± 1.0	4.8 ± 0.8	2.4 ± 0.4
Red Shiner	9.3 ± 2.1	4.6 ± 1.9	4.6 ± 0.9

Table 7. –Mean and range of parameters for non-native populations of 10 fish species in 12 western states 2000 - 2002.

Fish Species		Black bullhead	Brown trout	Channel catfish	Common carp
Stream order	Mean and 95% C.I.	2.4 + 1.4	3.4 + 0.5	4.4 + 3.0	5.0 + 0.4
	Value range	0.0 – 7.0	1.0 - 7.0	0.0 - 7.0	0.0 - 8.0
Mean cross-sectional area	Mean and 95% C.I.	1.4 + 3.1	3.5 + 1.3	N/A	5.4 + 2.1
	Value range	0.5 – 4.0	0.4 - 20	N/A	0.4 - 19.4
Velocity	Mean and 95% C.I.	0.00 + 0.01	0.09 + 0.01	N/A	0.05 + 0.04
	Value range	0.00 - 0.01	0.00 - 0.72	N/A	0.00 - 0.41
Mean stream gradient	Mean and 95% C.I.	0.9 + 2.0	2.5 + 0.6	N/A	0.7 + 0.2
	Value range	0.3 - 1.9	0.5 - 9.3	N/A	0.1 - 1.7
Percent of reach that is rapid and riffle	Mean and 95% C.I.	20.7 + 70.3	50.0 + 9.1	N/A	5.5 + 2.5
	Value range	0.5 - 50.0	3.0 - 99.9	N/A	0.5 - 26.0
Percent of reach that is glide and pool	Mean and 95% C.I.	79.5 + 70.9	50.0 + 9.1	N/A	94.4 + 2.6
	Value range	50.0 - 99.9	0.5 - 96.0	N/A	74.0 - 99.9
Mean annual precipitation	Mean and 95% C.I.	22.4 + 10.2	22.7 + 3.1	9.0 + 3.1	15.5 + 1.4
	Value range	10.0 - 32.5	7.5 - 65.0	7.5 - 17.5	5.0 - 45.0
Mean January minimum temperature	Mean and 95% C.I.	-3.5 + 1.4	-2.5 + 0.8	-1.9 + 1.2	-2.6 + 0.7
	Value range	-8.1 - -0.6	-8.1 - 0.6	-5.0 - 0.0	-6.1 - 0.6
Mean July maximum temperature	Mean and 95% C.I.	30.2 + 2.4	27.3 + 0.9	34.4 + 2.8	31.2 + 0.8
	Value range	29.4 - 38.3	18.3 - 35.0	29.4 - 38.3	23.9 - 38.3
Mean daily temperature change	Mean and 95% C.I.	13.4 + 4.4	6.4 + 0.9	9.0 + 4.9	5.5 + 1.0
	Value range	4.2 - 20.0	0 - 20.0	4.2 - 20.0	0.1 - 25.0
Mean substrate size	Mean and 95% C.I.	-0.9 + 4.2	1.5 + 0.3	N/A	-0.5 + 0.3
	Value range	-2.1 - 1.6	-1.5 - 2.5	N/A	-2.1 - 0.8
Percent instream fish cover	Mean and 95% C.I.	94.9 + 13.6	98.5 + 1.4	N/A	87.0 + 9.4
	Value range	90.1 - 99.9	72.2 - 99.9	N/A	1.0 - 99.9
Percent canopy cover	Mean and 95% C.I.	3.1 + 10.5	21.1 + 6.2	N/A	5.4 + 3.6
	Value range	<0.01 - 7.5	<0.01 - 76.6	N/A	<0.1 - 48.0
Level of level of human disturbance	Mean and 95% C.I.	3.4 + 0.7	3.6 + 0.2	2.9 + 0.7	2.6 + 0.2
	Value range	2 - 4	1 - 5	2 - 4	1 - 5
Human population density	Mean and 95% C.I.	110.2 + 13.8	162.2 + 80.9	62.1 + 58.0	74.9 + 28.9
	Value range	5.2 - 988	2.6 - 2613	5.2 - 174.2	2.6 - 988.0
Road density	Mean and 95% C.I.	24.3 + 22.5	29.3 + 5.5	7.7 + 12.0	36.8 + 5.9
	Value range	0 - 62	0 - 91.0	0.0 - 44.0	0.0 - 172.0

Table 7. –(Continued).

Fish Species		Fathead minnow	Green sunfish	Largemouth bass
Stream order	Mean and 95% C.I.	5.1 ± 1.1	4.2 ± 0.8	3.0 ± 1.2
	Value range	0.0 - 7.0	1.0 - 7.0	0.0 - 7.0
Mean cross-sectional area	Mean and 95% C.I.	2.8 ± 2.4	7.8 ± 3.9	2.9 ± 3.7
	Value range	0.5 - 4.6	0.5 - 19.4	0.3 - 11.1
Velocity	Mean and 95% C.I.	0.04 ± 0.06	0.10 ± 0.08	0.08 ± 0.12
	Value range	0.00 - 0.16	0.00 - 0.41	0.00 - 0.41
Mean stream gradient	Mean and 95% C.I.	0.7 ± 0.7	0.8 ± 0.3	2.9 ± 2.1
	Value range	0.1 - 1.6	0.1 - 1.9	0.4 - 4.9
Percent of reach that is rapid and riffle	Mean and 95% C.I.	23.3 ± 23.0	13.3 ± 10.7	25.1 ± 15.7
	Value range	5.4 - 50.0	0.5 - 50.0	0.5 - 38.7
Percent of reach that is glide and pool	Mean and 95% C.I.	76.7 ± 23.0	86.8 ± 10.8	74.6 ± 16.7
	Value range	50.0 - 94.6	50.0 - 99.9	60.7 - 99.9
Mean annual precipitation	Mean and 95% C.I.	11.2 ± 1.7	13.7 ± 1.2	26.6 ± 7.9
	Value range	7.5 - 27.5	7.5 - 22.5	7.5 - 45.0
Mean January minimum temperature	Mean and 95% C.I.	-1.4 ± 0.8	-1.8 ± 0.8	-3.5 ± 1.0
	Value range	-3.9 - 0.6	-8.1 - 0.6	-6.1 - 0.6
Mean July maximum temperature	Mean and 95% C.I.	32.4 ± 1.7	31.9 ± 0.9	31.1 ± 1.4
	Value range	23.9 - 38.3	29.4 - 38.3	23.9 - 38.3
Mean daily temperature change	Mean and 95% C.I.	5.9 ± 1.9	7.8 ± 2.8	13.1 ± 3.3
	Value range	4.2 - 20.0	0.1 - 25.0	0.1 - 25.0
Mean substrate size	Mean and 95% C.I.	0.8 ± 0.9	0.2 ± 0.7	0.7 ± 1.5
	Value range	-0.1 - 2.1	-2.1 - 2.1	-1.9 - 2.0
Percent instream fish cover	Mean and 95% C.I.	99.1 ± 1.2	91.6 ± 11.0	99.9 ± 0.0
	Value range	90.1 - 99.9	54.5 - 99.9	99.9 - 99.9
Percent canopy cover	Mean and 95% C.I.	2.0 ± 3.6	8.7 ± 8.0	22.3 ± 12.3
	Value range	<0.1 - 6.8	<0.1 - 32.0	<0.1 - 48.0
Level of level of human disturbance	Mean and 95% C.I.	2.8 ± 0.4	3.1 ± 0.4	2.7 ± 0.4
	Value range	1.0 - 4.0	1.0 - 4.0	1.0 - 5.0
Human population density	Mean and 95% C.I.	59.5 ± 64.5	281.6 ± 312.3	123.0 ± 68.9
	Value range	5.2 - 764.4	2.6 - 2904.2	2.6 - 988.0
Road density	Mean and 95% C.I.	29.3 ± 1.2	35.4 ± 11.0	41.5 ± 13.9
	Value range	0.0 - 82.0	0.0 - 98.0	0.0 - 91.0

Table 7. –(Continued).

Fish Species		Mosquitofish	Rainbow trout	Red shiner
Stream order	Mean and 95% C.I.	2.9 ± 1.0	4.2 ± 0.6	4.7 ± 1.0
	Value range	1.0 - 7.0	1.0 - 7.0	0.0 - 7.0
Mean cross-sectional area	Mean and 95% C.I.	3.9 ± 1.8	4.5 ± 2.7	8.7 ± 7.6
	Value range	0.1 - 7.1	0.1 - 24.8	0.5 - 19.4
Velocity	Mean and 95% C.I.	0.09 ± 0.03	0.07 ± 0.01	0.09 ± 0.01
	Value range	0.00 - 0.16	0.00 - 0.30	0.00 - 0.72
Mean stream gradient	Mean and 95% C.I.	0.8 ± 1.3	3.1 ± 1.6	0.9 ± 0.5
	Value range	0.1 - 1.7	0.5 - 12.1	0.3 - 1.6
Percent of reach that is rapid and riffle	Mean and 95% C.I.	12.7 ± 11.4	51.5 ± 10.9	25.0 ± 14.6
	Value range	0.5 - 50.0	0.5 - 90.0	8.0 - 50.0
Percent of reach that is glide and pool	Mean and 95% C.I.	87.3 ± 11.4	48.3 ± 10.6	75.0 ± 14.6
	Value range	50.0 - 99.9	10.0 - 99.9	50.0 - 92.0
Mean annual precipitation	Mean and 95% C.I.	11.0 ± 2.6	19.6 ± 2.1	12.3 ± 2.2
	Value range	5.0 - 17.5	7.5 - 40.0	5.0 - 22.5
Mean January minimum temperature	Mean and 95% C.I.	-1.0 ± 0.9	-2.8 ± 0.7	-1.8 ± 0.9
	Value range	-6.1 - 0.6	-8.1 - 0.6	-5.0 - 0.6
Mean July maximum temperature	Mean and 95% C.I.	35.8 ± 1.4	27.7 ± 1.0	33.3 ± 1.7
	Value range	23.9 - 38.3	18.3 - 38.3	29.4 - 38.3
Mean daily temperature change	Mean and 95% C.I.	16.6 ± 2.9	5.9 ± 1.0	8.1 ± 3.1
	Value range	4.2 - 25.0	0.1 - 15.8	0.1 - 20.0
Mean substrate size	Mean and 95% C.I.	-0.3 ± 0.9	1.7 ± 0.3	0.7 ± 0.6
	Value range	-2.1 - 2.1	0.5 - 2.6	0.2 - 1.5
Percent instream fish cover	Mean and 95% C.I.	99.9 ± 0.0	98.6 ± 1.4	92.3 ± 13.0
	Value range	99.9 - 99.9	90.9 - 99.9	63.6 - 99.9
Percent canopy cover	Mean and 95% C.I.	16.4 ± 7.1	26.6 ± 9.2	6.9 ± 12.7
	Value range	<0.1 - 32.0	<0.1 - 76.6	<0.1 - 32.0
Level of level of human disturbance	Mean and 95% C.I.	1.9 ± 0.5	3.4 ± 0.3	3.2 ± 0.4
	Value range	1.0 - 4.0	1.0 - 5.0	2.0 - 4.0
Human population density	Mean and 95% C.I.	545.5 ± 516.1	121.9 ± 75.9	40.8 ± 20.5
	Value range	5.2 - 2904.2	2.6 - 1414.4	5.2 - 174.2
Road density	Mean and 95% C.I.	47.5 ± 7.7	24.7 ± 6.4	23.9 ± 8.6
	Value range	0.0 - 98.0	0.0 - 67.0	0.0 - 51.0

Table 8. – Relationships (t-tests) of presence of 10 fish species and biotic, abiotic and human variables in 12 western states 2000 – 2002.

	Red shiner present		Rainbow trout present		Large-mouth bass present		Mosquito-fish present		Green sunfish present		Fathead minnow present	
	t	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*
Stream order	-6.2	<0.01	-2.8	0.01	-0.6	0.56	-0.3	<0.01	-4.9	<0.01	-7.4	<0.01
Mean stream gradient *log*	3.2	<0.01	-0.9	0.38	0.6	0.59	2.2	0.03	3.8	<0.01	6.5	<0.01
Velocity *log*	1.0	0.31	-1.7	0.08	0.9	0.35	-0.5	0.58	1.0	0.32	2.5	0.01
Mean July maximum temperature	-7.1	<0.01	-3.4	<0.01	-4.5	<0.01	-5.8	<0.01	-6.3	<0.01	-7.2	<0.01
Mean January minimum temperature	-3.8	<0.01	-2.2	0.03	-1.5	0.15	-3.6	<0.01	-4.3	<0.01	-5.9	<0.01
Mean daily temperature change	2.8	<0.01	-6.8	<0.01	-2.8	<0.01	-3.1	<0.01	2.9	<0.01	7.1	<0.01
Mean annual precipitation *log*	5.2	<0.01	-1.8	0.08	1.8	0.07	4.5	<0.01	5.3	<0.01	8.3	<0.01
Mean cross-sectional area *log*	-2	0.05	-1.8	0.08	-0.1	0.89	-1.3	0.2	-2.8	<0.01	-2.8	<0.01
Percent canopy cover *logit*	1.8	0.08	-4.1	<0.01	0	0.97	0.2	0.81	2.8	<0.01	7.1	<0.01
Percent instream fish cover *logit*	1	0.31	-2.3	0.02	-0.8	0.4	-0.9	0.39	2.1	0.04	1.5	0.14
Mean substrate size *log*	2.7	<0.01	-7.4	<0.01	0.5	0.63	2.1	0.04	3.5	<0.01	6.1	<0.01
Percent of reach that is rapid and riffle *logit*	2.1	0.04	-3.2	<0.01	1.2	0.23	2.1	0.04	3.4	<0.01	6.3	<0.01
Percent of reach that is glide and pool *logit*	-2.1	0.03	2.4	0.02	-1.6	0.11	-2.3	0.02	-3.8	<0.01	-7.1	<0.01
Human population density *log*	1.7	0.1	-5.2	<0.01	-1.9	0.05	-1.8	0.07	1.5	0.14	3.5	<0.01
Level of level of human disturbance	1.9	0.05	0.1	0.93	4.5	<0.01	4.3	<0.01	1.9	0.06	2.3	0.02
Road density *log*	-0.8	0.4	-0.3	0.76	-2.5	0.01	-2.3	0.02	-1.6	0.12	-1.3	0.21

Table 8. –(Continued).

	Fathead minnow present		Common carp present		Channel catfish present		Brown trout present		Black bullhead present	
	t	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*
Stream order	-7.4	<0.01	-10	<0.01	-9.6	<0.01	-4	<0.01	-3.8	<0.01
Mean stream gradient *log*	6.5	<0.01	5.4	<0.01	4.3	<0.01	0.9	0.32	4.1	<0.01
Velocity *log*	2.5	0.01	2.6	0.01	0.8	0.40	-1.9	0.06	1.2	0.23
Mean July maximum temperature	-7.2	<0.01	-8.6	<0.01	-5.9	<0.01	-2.2	0.03	-3.9	<0.01
Mean January minimum temperature	-5.9	<0.01	-5.5	<0.01	-3.9	<0.01	-7.7	<0.01	-1.1	0.28
Mean daily temperature change	7.1	<0.01	4.9	<0.01	5.3	<0.01	4.8	<0.01	3.9	<0.01
Mean annual precipitation *log*	8.3	<0.01	8.6	<0.01	6.2	<0.01	5.9	<0.01	3.6	<0.01
Mean cross-sectional area *log*	-2.8	<0.01	-3.5	<0.01	-4.1	<0.01	-3.2	<0.01	-2	0.05
Percent canopy cover *logit*	7.1	<0.01	5.2	<0.01	3.7	<0.01	0.6	0.55	3.4	<0.01
Percent instream fish cover *logit*	1.5	0.14	2.9	<0.01	2.7	<0.01	-1.2	0.25	2.4	0.02
Mean substrate size *log*	6.1	<0.01	4.8	<0.01	2.6	<0.01	-2.4	0.02	5	<0.01
Percent of reach that is rapid and riffle *logit*	6.3	<0.01	5.5	<0.01	3.9	<0.01	-1.5	0.13	4.8	<0.01
Percent of reach that is glide and pool *logit*	-7.1	<0.01	-6.3	<0.01	-4.5	<0.01	0.8	0.44	-5	<0.01
Human population density *log*	3.5	<0.01	1.7	0.09	3.5	<0.01	-2.2	0.03	0.3	0.73
Level of level of human disturbance	2.3	0.02	5.6	<0.01	1.3	0.2	0.6	0.55	2.6	<0.01
Road density *log*	-1.3	0.21	-3	<0.01	0.4	0.7	-1.9	0.06	-2	0.04

Table 9. – Relationships (correlations) of relative abundance (logit transformed) of 10 fish species and biotic, abiotic and human variables in 12 western states 2000 – 2002.

		Red shiner	Rainbow Trout	Largemouth Bass	Mosquito-fish	Green sunfish
Stream order	*r*	-0.21	-0.16	0.34	-0.65	0.32
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean January minimum temperature	*r*	0.24	-0.11	0.15	0.15	0.11
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean July maximum temperature	*r*	0.14	-0.12	0.44	0.46	0.20
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean daily temperature change	*r*	0.31	0.12	0.48	0.46	0.17
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean annual precipitation *log*	*r*	-0.05	0.23	0.32	-0.86	-0.05
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Velocity *log*	*r*	0.56	0.02	-0.40	0.23	-0.36
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean cross-sectional area *log*	*r*	0.52	-0.08	-0.35	-0.25	0.15
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean stream gradient *log*	*r*	0.38	0.11	0.61	-0.49	-0.47
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Percent canopy cover *logit*	*r*	0.19	0.10	0.26	-0.68	-0.06
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Percent instream fish cover *logit*	*r*	0.39	0.16	0.47	0.48	0.23
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean substrate size *log*	*r*	0.11	0.01	0.76	-0.61	-0.27
	P	<0.01	0.29	<0.01	<0.01	<0.01
Percent of reach that is rapid and riffle *logit*	*r*	0.12	0.03	0.84	-0.44	-0.43
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Percent of reach that is glide and pool *logit*	*r*	0.07	0.10	-0.85	0.34	0.37
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Human population density *log*	*r*	0.07	-0.05	-0.32	-0.22	-0.16
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Road density *log*	*r*	-0.01	0.03	-0.33	0.29	-0.22
	P	0.68	<0.01	<0.01	<0.01	<0.01
Level of level of human disturbance	*r*	0.01	0.24	0.36	-0.65	0.46
	P	0.39	<0.01	<0.01	<0.01	<0.01

Table 9. –(Continued).

		Fathead minnow	Common carp	Channel catfish	Brown trout	Black bullhead
Stream order	*r*	-0.15	-0.09	-0.06	-0.16	-0.25
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean January	*r*	0.23	-0.14	-0.04	-0.15	-0.09
minimum temperature	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean July maximum	*r*	-0.39	0.31	0.42	-0.04	-0.17
temperature	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean daily	*r*	-0.13	0.10	0.18	0.09	-0.13
temperature change	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean annual	*r*	0.12	-0.25	-0.14	-0.07	0.27
precipitation *log*	P	<0.01	<0.01	<0.01	<0.01	<0.01
Velocity *log*	*r*	-0.32	0.07	-0.34	0.17	0.09
	P	<0.01	<0.01	<0.01	<0.01	0.30
Mean cross-sectional	*r*	-0.52	0.17	-0.26	-0.11	-0.11
area *log*	P	<0.01	<0.01	<0.01	<0.01	<0.01
Mean stream gradient	*r*	0.36	-0.12	-0.40	-0.02	-0.28
log	P	<0.01	<0.01	<0.01	0.09	<0.01
Percent canopy cover	*r*	-0.06	0.25	0.29	0.09	-0.15
logit	P	<0.01	<0.01	<0.01	<0.01	<0.01
Percent instream fish	*r*	-0.05	0.01	0.47	-0.19	-0.42
cover *logit*	P	<0.01	.586	<0.01	<0.01	<0.01
Mean substrate size *log*	*r*	-0.05	-0.37	-0.53	-0.12	-0.10
	P	<0.01	<0.01	<0.01	<0.01	<0.01
Percent of reach that is	*r*	-0.17	0.13	0.09	0.25	-0.29
rapid and riffle *logit*	P	<0.01	<0.01	<0.01	<0.01	<0.01
Percent of reach that is	*r*	0.11	-0.06	-0.09	-0.26	-0.10
glide and pool *logit*	P	<0.01	<0.01	<0.01	<0.01	<0.01
Human population	*r*	-0.07	0.38	0.07	-0.05	-0.15
density *log*	P	<0.01	<0.01	<0.01	<0.01	<0.01
Road density *log*	*r*	0.16	0.04	0.07	-0.27	-0.02
	P	<0.01	<0.01	<0.01	<0.01	0.10
Level of level of	*r*	0.05	-0.23	-0.30	0.20	-0.12
human disturbance	P	<0.01	<0.01	<0.01	<0.01	<0.01

Table 10. -Factors most associated with 10 non-native fish species presence in 12 western states 2000 - 2002.

Model	Terms	Slope	*SE*	*P*	R^2	*d.f.*	Classification Table* (% correctly predicted by cross-validation)	
Black bullhead Presence	Substrate size *Log*	-5.47	0.24	<0.01	0.77	323	Absent	99.8
	July temperature	0.41	0.02	<0.01			Present	0.1
	Level of human disturbance	5.94	0.30	<0.01			Total	99.3
	Daily temperature change	0.44	0.02	<0.01				
	Road density *Log*	-2.13	0.15	<0.01				
	Intercept	-72.31	3.50	<0.01				
Brown trout Presence	January temperature	0.15	<0.01	<0.01	0.26	394	Absent	98.7
	Substrate size *Log*	0.33	0.02	<0.01			Present	3.6
	Precipitation *Log*	-2.00	0.03	<0.01			Total	93.2
	Daily temperature change	-0.04	<0.01	<0.01				
	Intercept	-1.04	0.15	<0.01				
Channel catfish Presence	Land-use			0.02	0.43	105	Absent	99.4
	Agriculture	2.32	8.94				Present	8.3
	Forest	-1.11	8.97				Total	96.6
	Range	1.84	8.93					
	Suburban/Town	-6.44	8.95					
	Urban	3.39	8.95					
	Order	0.86	0.11	0.03				
	Level of human disturbance	0.42	0.20	0.02				
	Intercept	-9.01	8.98	0.32				
Common carp Presence	Stream order	0.67	0.02	<0.01	0.50	387	Absent	99.2
	Rapid and riffle *Logit*	-0.24	0.01	<0.01			Present	19.2
	July temperature	0.21	<0.01	<0.01			Total	94.0
	Canopy cover *Logit*	-0.22	<0.01	<0.01				
	Daily temperature change	-0.08	<0.01	<0.01				
	Intercept	-23.39	0.44	<0.01				

* Cut-point = 0.5, counting a species present at a site if it is more than 50% likely to be there.

Table 10. –(Continued).

Model	Terms	Slope	*SE*	*P*	R^2	*d.f.*	Classification Table* (% correctly predicted by cross-validation)	
Fathead minnow Presence	Land-use			<0.01	0.49	320	Absent	99.7
	Agriculture	-5.90	23.34				Present	8.4
	Forest	-3.73	26.35				Total	99.1
	Range	8.60	22.96					
	Suburban/Town	5.96	22.99					
	Urban	4.94	24.56					
	Instream cover *Logit*	0.37	0.04	<0.01				
	Gradient *Log*	-1.71	0.07	<0.01				
	January temperature	0.61	0.02	<0.01				
	Substrate size *Log*	1.06	0.06	<0.01				
	Population	0.82	0.06	<0.01				
	Order	-0.58	0.05	<0.01				
	Intercept	-29.12	0.86	<0.01				
Green sunfish Presence	Land-use			<0.01	0.61	372	Absent	99.4
	Agriculture	-8.48	22.37				Present	17.3
	Forest	-2.09	26.35				Total	98.7
	Range	2.50	22.96					
	Suburban/Town	5.96	22.99					
	Urban	4.94	24.67					
	July temperature	0.21	<0.01	<0.01				
	Canopy cover *Logit*	-0.73	0.03	<0.01				
	Cross-sectional area *Log*	1.39	0.04	<0.01				
	Level of disturbance	1.60	0.07	<0.01				
	Daily temperature change	0.19	<0.01	<0.01				
	Intercept	-37.97	2.32	<0.01				
Largemouth bass Presence	Land-use			<0.01	0.63	350	Absent	99.4
	Agriculture	1.94	3.05				Present	17.3
	Forest	-3.62	3.05				Total	98.3
	Range	3.88	3.04					
	Suburban/Town	-6.87	3.05					
	Urban	4.67	3.05					
	July temperature	0.33	0.01	<0.01				
	Run and pool *Logit*	0.43	0.02	<0.01				
	Precipitation	3.08	0.14	<0.01				
	Intercept	-46.92	3.32	<0.01				

* Cut-point = 0.5, counting a species present at a site if it is more than 50% likely to be there.

Table 10. –(Continued).

Model	Terms	Slope	*SE*	*P*	R^2	*d.f.*	Classification Table* (% correctly predicted by cross-validation)	
Mosquitofish Presence	Land-use			<0.01	0.67	370	Absent	99.6
	Agriculture	2.03	3.05				Present	9.4
	Forest	-9.05	3.05				Total	99.3
	Range	0.97	3.05					
	Suburban/Town	1.53	3.05					
	Urban	4.52	3.05					
	July temperature	0.19	<0.01	<0.01				
	January temperature	0.50	0.03	<0.01				
	Gradient *Log*	-1.34	0.06	<0.01				
	Population *Log*	0.89	0.04	<0.01				
	Intercept	-39.80	3.18	<0.01				
Rainbow trout Presence	Order	0.95	0.02	<0.01	0.35	398	Absent	99.5
	Substrate size *Log*	1.93	0.03	<0.01			Present	15.2
	Precipitation *Log*	-3.14	0.06	<0.01			Total	96.9
	July temperature	-0.12	<0.01	<0.01				
	Population *Log*	0.29	0.01	<0.01				
	Intercept	9.97	0.34	<0.01				
Red shiner Presence	July temperature	0.31	0.01	<0.01	0.55	368	Absent	99.8
	January temperature	0.61	0.03	<0.01			Present	16.2
	Canopy cover *Logit*	-0.47	0.02	<0.01			Total	99.3
	Level of disturbance	1.13	0.06	<0.01				
	Intercept	-55.93	1.44	<0.01				

* Cut-point = 0.5, counting a species present at a site if it is more than 50% likely to be there.

Table 11. -Factors most related to the *Logit* transformed relative abundance of 10 non-native fish species in 12 western states in 2000 - 2002.

Model	Terms	Slope	SE	*P*	R^2	d.f.	AIC	Coorelation of predicted and actual value (*r*)
Black bullhead	January temperature	-0.50	0.24	0.05	0.32	24	79.2	0.42
Relative	Instream cover *Logit*	-0.39	0.13	<0.01				
Abundance	Intercept	12.12	6.21	0.06				
Brown trout	Substrate size *Log*	-1.68	0.74	0.03	0.33	36	302.1	0.13
Relative	Run or pool *Logit*	-1.09	0.37	<0.01				
Abundance	Population *Log*	1.01	0.41	0.02				
	Road density *Log*	-0.95	0.35	0.01				
	Intercept	1.98	1.64	0.24				
Channel catfish	Substrate *Log*	-1.30	0.60	<0.01	0.28	13	75.6	0.18
Relative	Intercept	-4.10	0.34	0.05				
Abundance								
Common carp	July temperature	0.11	0.04	>0.01	0.21	96	133.5	0.28
Relative	Population *Log*	0.54	0.15	>0.01				
Abundance	Intercept	-14.30	3.47	>0.01				
Fathead minnow	July temperature	-0.41	0.10	>0.01	0.48	48	257.9	0.33
Relative	Mean cross-sectional area *Log*	-1.24	0.36	>0.01				
Abundance	Road density *Log*	0.51	0.26	0.06				
	Intercept	32.51	8.72	>0.01				
Green sunfish	Gradient *Log*	-1.25	-0.92	0.21	0.17	10	68.4	-0.13
Relative	Intercept	-3.15	0.70	<0.01				
Abundance								
Non-native only								
Mosquitofish	Daily temperature change	0.31	0.08	<0.01	0.71	17	57.0	0.14
Relative	Level of human disturbance	-4.32	0.83	<0.01				
Abundance	Intercept	-0.33	2.86	0.91				
Rainbow trout	Cross-sectional area *Log*	-1.07	0.47	0.04	0.62	14	85.4	-0.20
Relative	Rapid and riffle *Logit*	-0.81	0.32	0.02				
Abundance	Intercept	-0.81	0.68	0.25				
Non-native only								

Table 12. -Percent of stream length, by land-use, in which selected species were distributed in 12 western states 2000 - 2002.

	Forest	Range	Agriculture	Suburban/Town	Urban
Black Bullhead	<0.1	0.7	2.7	12.3	-
Brown Trout	10.3	19.7	15.9	5.9	9.7
Channel Catfish	0.2	1.4	-	-	-
Common Carp	0.2	18.5	28.6	7.9	8.0
Fathead Minnow	0.6	5.6	1.1	2.3	-
Green Sunfish	0.5	4.3	3.8	8.2	14.2
Largemouth Bass	<0.1	5.1	8.6	5.0	26.2
Mosquitofish	-	1.5	4.8	3.2	14.2
Rainbow Trout	5.9	19.0	11.4	5.0	-
Red Shiner	0.6	3.4	3.3	1.7	-

Figure 1. –Distribution of native and non-native populations of 10 fish species in streams of 12 western states 2000 – 2002.

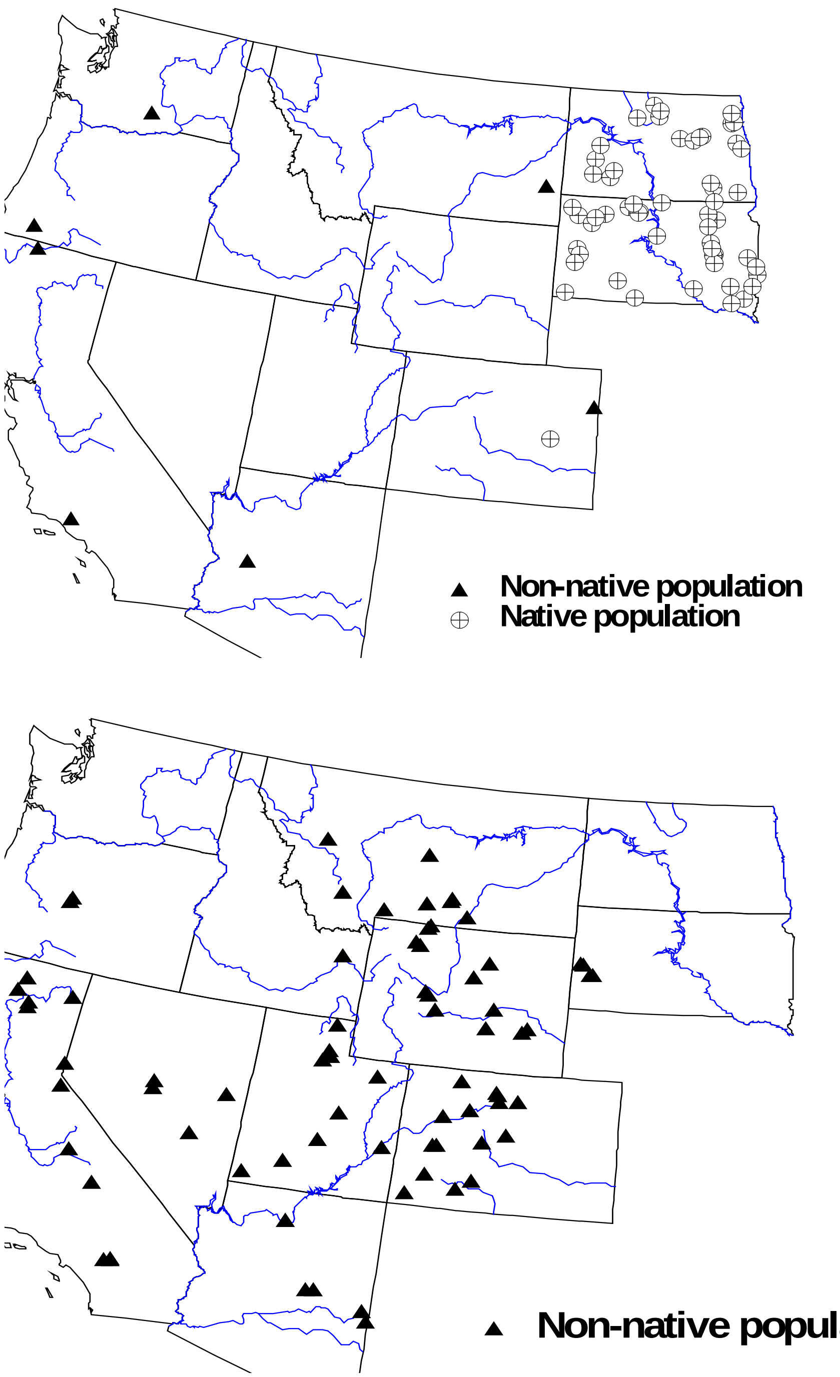
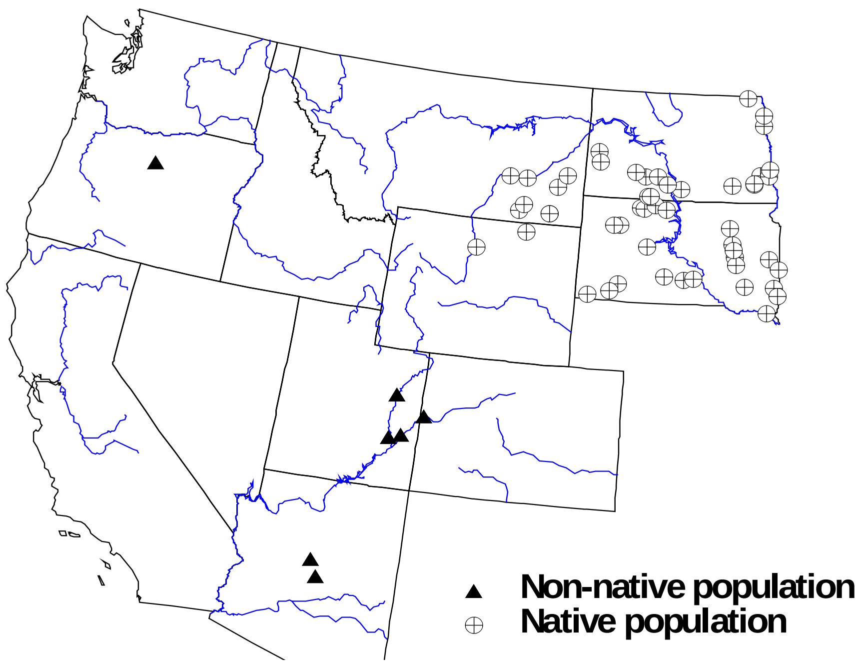


Figure 1. – (Continued).



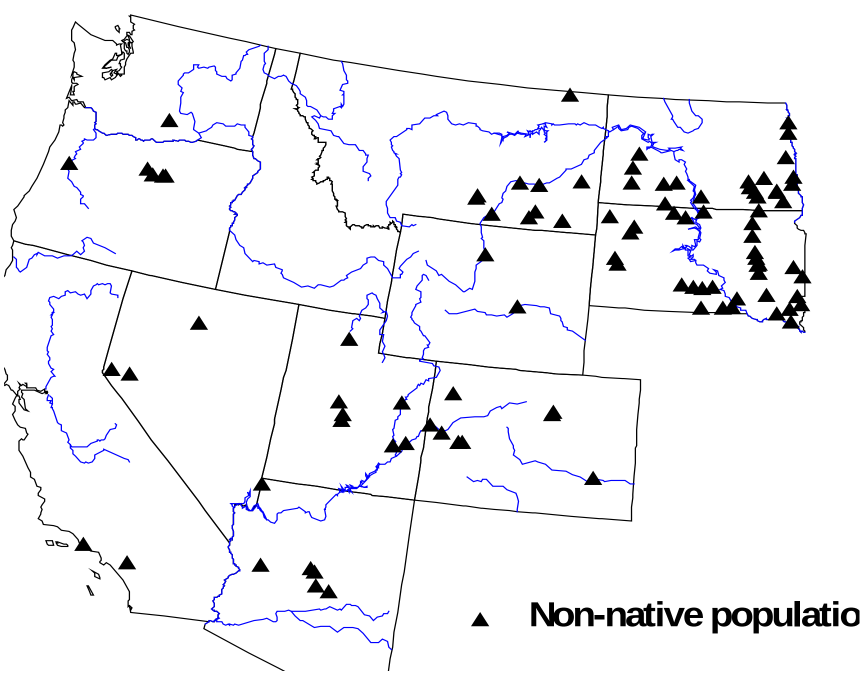
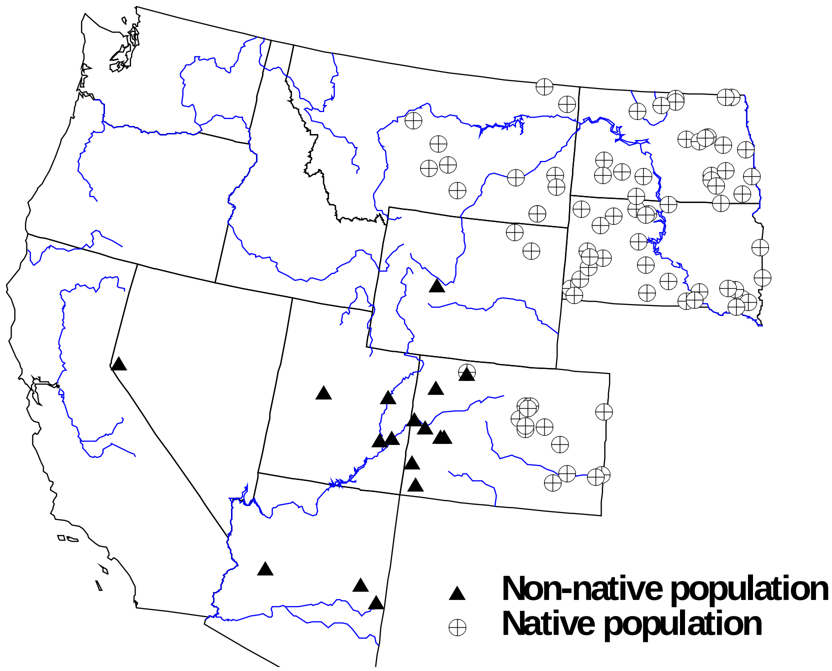


Figure 1. – (Continued).



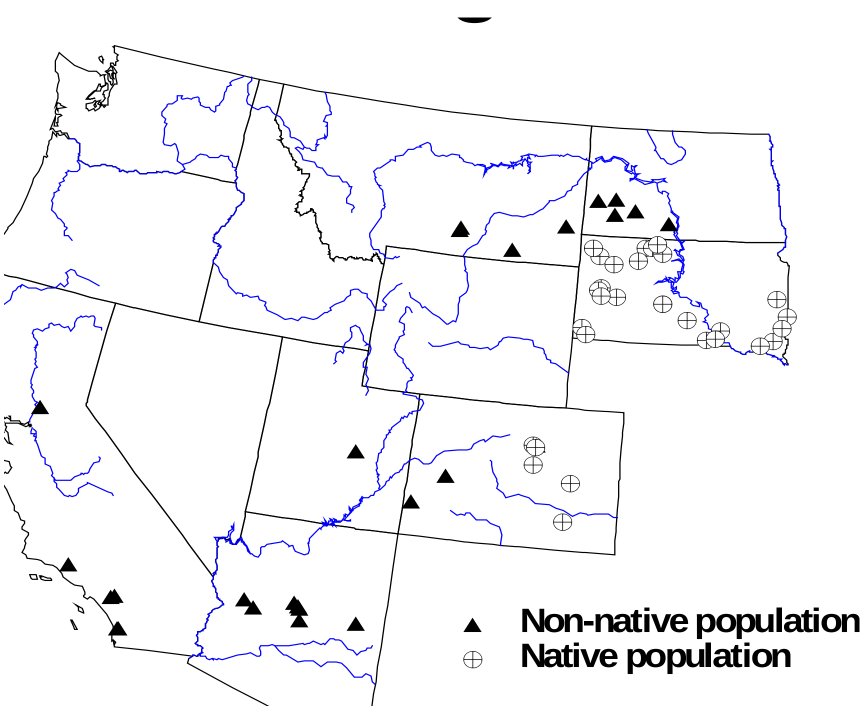
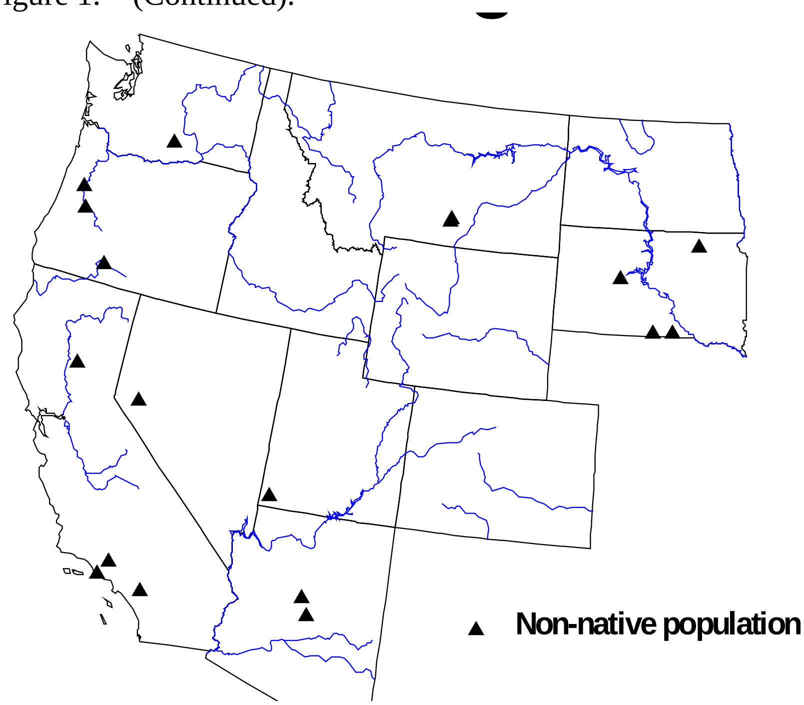


Figure 1. – (Continued).



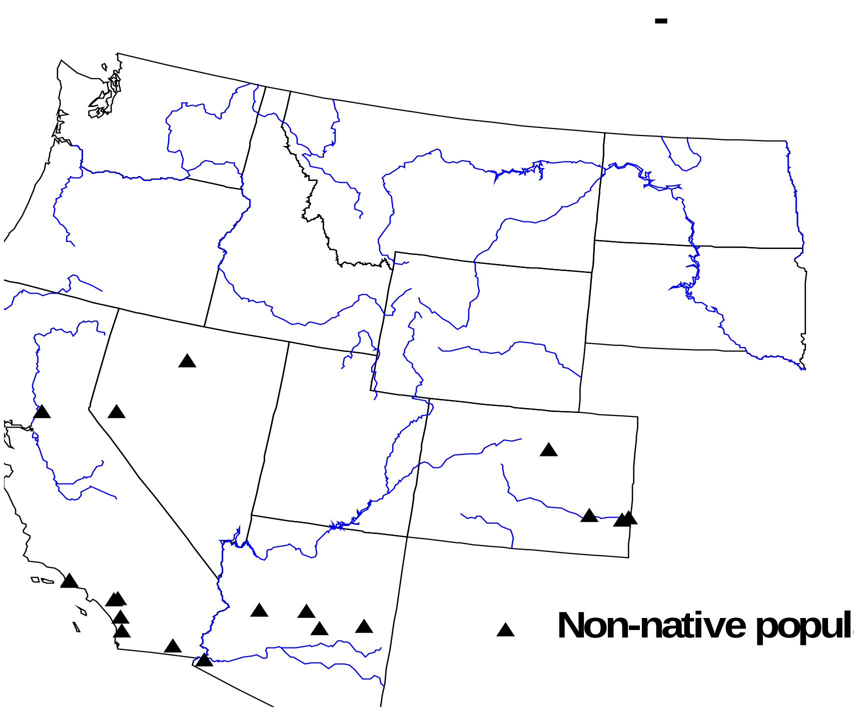


Figure 1. – (Continued).