Introduction, establishment and ecological impacts of non-indigenous fishes in the Lower Colorado River Basin

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Lower Colorado River Basin Aquatic Gap Analysis Project

Outline

- The United States perspective
- Lower Colorado River Basin
  - Pathways of introduction
  - Patterns of establishment and rates of spread
  - Non-indigenous fishes and species distributions in the Upper Gila River Basin
  - Ecological impacts of non-indigenous fish
- What science is needed to inform the decision-making process?

What is a non-indigenous species?

A species is regarded as *non-indigenous* (or non-native) if it has been introduced by human action to a location, area, or region where it did not previously occur naturally, becomes capable of establishing a breeding population in the new location without further intervention by humans, and spreads widely throughout the new location.

A species is regarded as *invasive* if it causes significant ecological, evolutionary or economic harm.

The United States perspective

- The spread of non-indigenous species (NIS) introduced into the U.S. is a significant and growing national problem
- Some NIS species are introduced intentionally and are highly valued by humans, while many other species are introduced as by-products of human activity
- NIS cost taxpayers hundreds of billions of dollars in environmental degradation, lost agricultural productivity, increased health problems, and expensive prevention and eradication efforts (Pimental et al. 2000, 2005)

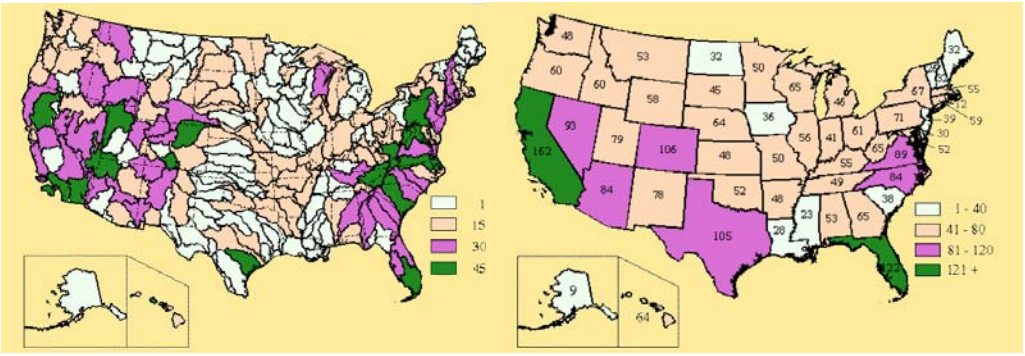
Primary threats to freshwater fishes

- Habitat loss and modification
- Dams and altered flow regimes
- Over-exploitation
- Pollution
- Climate change
- Non-indigenous fish species

"The accelerating introduction and spread of invasive species is among the most serious of threats to global biodiversity"

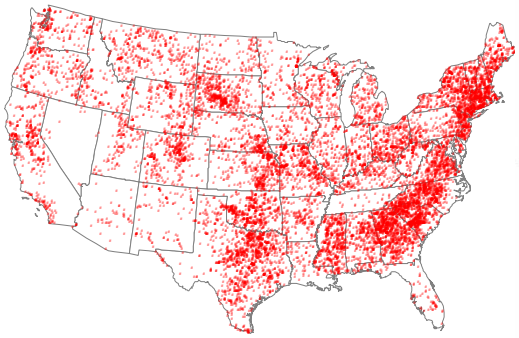
Union of Concerned Scientists (2003)

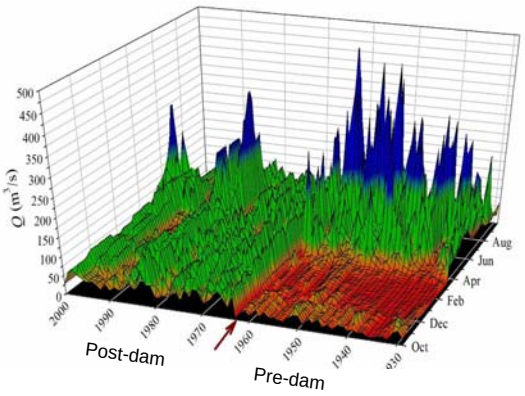
Non-indigenous fishes in the U.S.



Nonindigenous Aquatic Species Database
U.S. Geological Survey

Dammed nation





USACE National Inventory of Dams

Green River, UT
below Flaming Gorge Reservoir

Non-indigenous fishes in western U.S.

- Native fish faunas in western streams are low in diversity, high in endemism, and extremely vulnerable to non-native invasions (Minckley and Deacon 1968, 1991)

TABLE 1.—Distribution and relative abundance of nonnative fishes in fish-bearing streams and 95% confidence intervals by state.

State	Stream length (% of total) with nonnative fishes present	Stream length (% of total) with only native fishes	Relative abundance (%) of nonnative fish for entire state	Total number of species detected	Percent of total species that are nonnative
Arizona	66.7 ± 17.0	14.0 ± 12.4	50.5 ± 19.0	27	59.3
California	43.0 ± 15.1	40.0 ± 14.9	25.6 ± 9.2	53	39.6
Colorado	72.6 ± 13.7	9.4 ± 9.0	66.0 ± 10.8	36	52.8
Idaho	25.1 ± 14.7	42.0 ± 16.8	20.4 ± 10.4	21	14.3
Montana	68.6 ± 20.5	14.1 ± 15.4	22.9 ± 11.3	57	31.6
Nevada	44.1 ± 17.0	37.2 ± 16.6	40.5 ± 20.3	71	18.3
North Dakota	60.9 ± 15.4	35.6 ± 15.0	10.8 ± 8.5	23	52.2
Oregon	23.8 ± 13.6	60.8 ± 15.6	13.3 ± 14.4	53	24.5
South Dakota	53.1 ± 14.5	44.9 ± 14.4	38.5 ± 16.0	73	23.3
Utah	65.8 ± 16.5	20.0 ± 13.9	12.3 ± 11.0	41	41.5
Washington	17.7 ± 13.5	48.9 ± 16.7	42.3 ± 12.3	38	18.4
Wyoming	47.0 ± 18.0	25.8 ± 14.8	8.2 ± 17.0	35	25.7

Schade, C.B., and S.A Bonar. 2005. Distribution and abundance of nonnative fishes in streams of the western United States. NAJMF 25: 1386-1394.

Colorado River Basin

- The Colorado River has played a pivotal role in the growth of the American Southwest
- Provides irrigation water for more than 4 million acres of farmland and delivers water and electricity to 30 million people in the U.S. and Mexico
- One of the most controlled rivers on the Earth

The Invasion Process

Invasion is a multi-step process comprised of three phases:

Introduction

An organism moves from its native habitat, often over long distances, to a new habitat outside of its home range

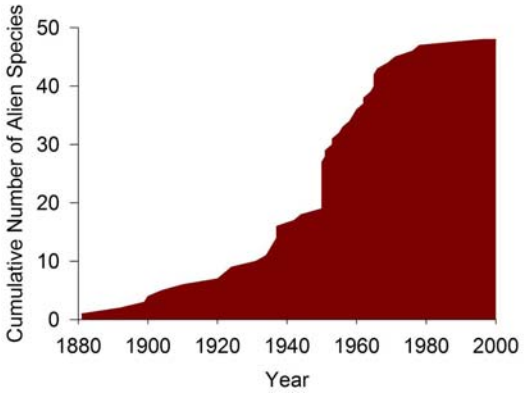
Establishment

Creation of a self-sustaining population within the new habitat, and spread of the organism to nearby habitats

Integration

Incorporation into the native community with possible ecological and/or economic impacts

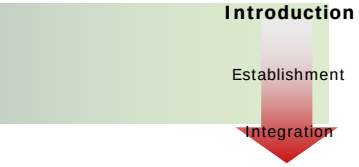
Non-indigenous fishes of the LCR Basin



- Over 100 species have been introduced, half of which are considered established (Rinne and Janisch 1995)
- There are numerous pathways of introduction, whose relative importance have changed over time

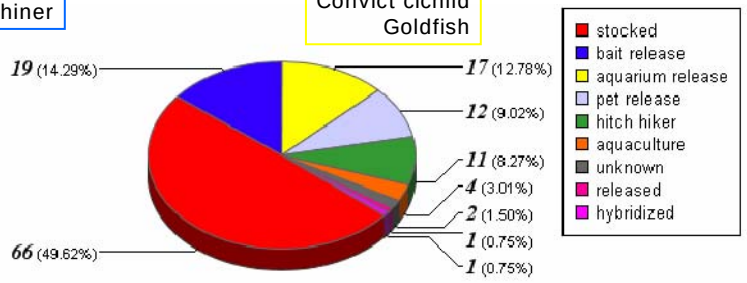
Sources: Marsh and Pacey 2003, Olden and Poff (2005), SONFISHES

Pathways of introduction



Fathead minnow
Red shiner
Golden shiner

Sailfin molly
Guppy
Convict cichlid
Goldfish



Small/largemouth bass
Brown/black/yellow bullhead
Grass/common carp
Green sunfish
Brown/rainbow/brook trout

Mozambique tilipia
Common/bighead carp
Nile tilipia

Nonindigenous Aquatic Species Database
U.S. Geological Survey, 2006

Factors influencing establishment

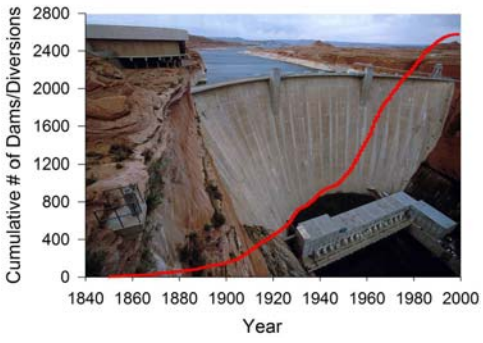
Introduction
Establishment
Integration

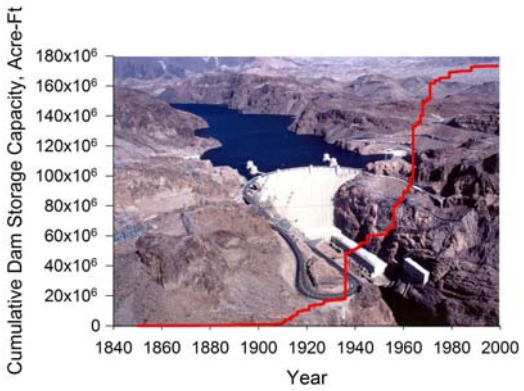
A number of factors favor the establishment of non-indigenous fishes:

- Altered flow and thermal regimes caused by dams and diversions
- Habitat loss, modification, and fragmentation
- Land use change and degradation of riparian zones
- Sources of environmental disturbance (e.g., pollution)

- Low biological resistance of native communities

Dams and diversions

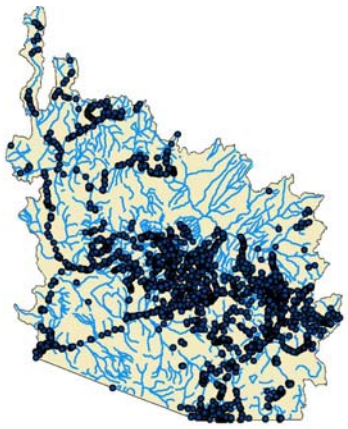




U.S. Army Corp of Engineers: National Inventory of Dams (2006)

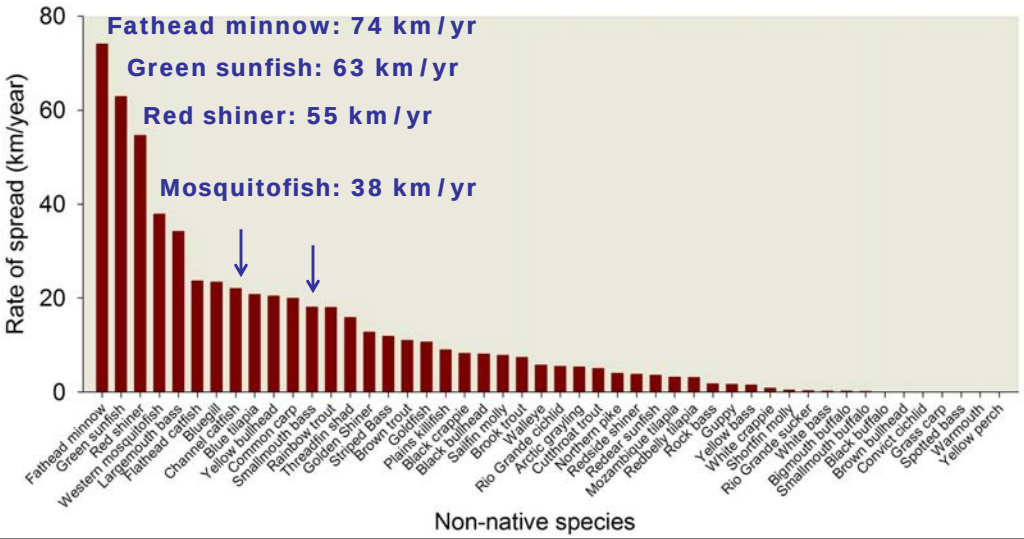
Patterns of establishment

- Research suggests that non-native species distributions have changed dramatically over time
- Olden and Poff (2005) analyzed 28,755 occurrence records for 47 non-native species collected between 1840 and 2000
- Quantified the total river kilometers occupied by each species over time



Olden, J.D. and N.L. Poff. 2005. Long-term trends of native and non-native fish faunas in the American Southwest. Animal Biodiversity and Conservation 28: 75-89.

Rates of spread during the 20th century

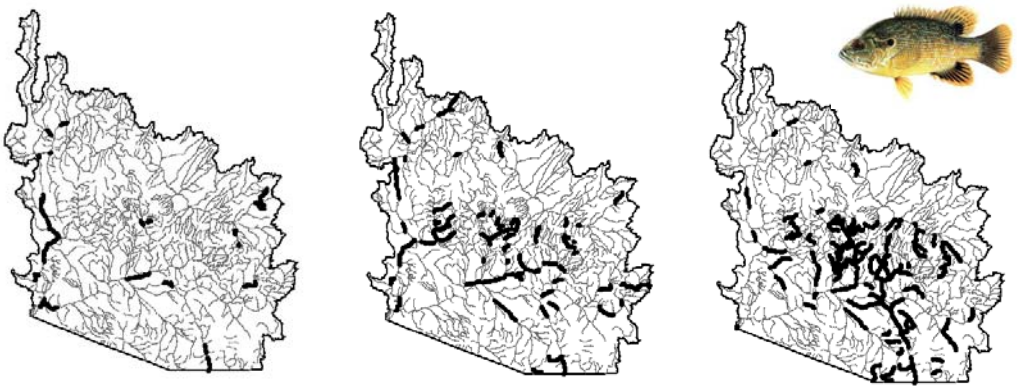


Temporal patterns of species ranges

Species	C	I	Temporal trends <1960	1960s	1970s	1980s	1990s	ER	S
Fathead minnow (*Pimephales promelas*)	1	1950	1.9	7.7	21.8	28.7	39.2	39.3	74.1
Green sunfish (*Lepomis cyanellus*)	2	1937	11.4	16.9	19.8	30.9	44.1	42.0	62.9
Red shiner (*Cyprinella lutrensis*)	3	1950	0.9	17.4	18.7	27.4	27.9	28.9	54.6
Western mosquitofish (*Gambusia affinis*)	4	1922	15.4	16.5	19.2	28.1	27.5	31.3	37.9
Largemouth bass (*Micropterus salmoides*)	5	1935	9.2	15.3	11.6	20.6	19.9	23.6	34.2
Flathead catfish (*Pylodictis olivaris*)	6	1962	1.0	0.6	3.1	9.3	9.3	9.5	23.7
Bluegill (*Lepomis macrochirus*)	7	1937	8.0	8.2	7.2	12.8	12.7	15.6	23.4
Channel catfish (*Ictalurus punctatus*)	8	1892	11.2	15.1	14.6	27.5	15.4	25.2	22.0
Blue tilapia (*Oreochromis aureus*)	9	1978	0.0	0.0	0.3	5.9	1.0	4.8	20.7
Yellow bullhead (*Ameiurus natalis*)	10	1899	5.7	7.6	10.9	16.3	21.8	21.9	20.4
Common carp (*Cyprinus carpio*)	11	1881	14.0	16.5	15.8	21.7	21.2	25.1	19.9
Smallmouth bass (*Micropterus dolomieui*)	12	1942	2.8	3.5	5.2	10.8	10.1	11.1	18.0
Rainbow trout (*Oncorhynchus mykiss*)	13	1900	12.4	18.7	23.3	16.7	20.3	19.1	18.0

Green sunfish (*Lepomis cyanellus*)

Pre-1960 → 1960-80 → 1981-2000



- Green sunfish has been shown to negatively affect native fishes, including the recruitment of Gila chub (*Gila intermedia*) (Dudley and Matter 2000)

Non-indigenous fishes of the Upper Gila River Basin

- Published literature suggests that 19 non-indigenous species have been observed in the Upper Gila River Basin
- These include many nuisance species with known ecological impacts on native fish communities

Scientific name	Common name
Ameiurus melas	black bullhead
Ameiurus natalis	yellow bullhead
Catostomus plebeius	Rio Grande sucker
Cyprinus carpio	common carp
Cyprinella lutrensis	red shiner
Gambusia affinis	mosquitofish
Ictalurus lupus	headwater catfish
Ictalurus punctatus	channel catfish
Lepomis cyanellus	green sunfish
Lepomis macrochirus	bluegill
Micropterus dolomieu	smallmouth bass
Micropterus salmoides	largemouth bass
Oncorhynchus mykiss	rainbow trout
Pimephales promelas	fathead minnow
Pylodictis olivaris	flathead catfish
Salmo trutta	brown trout

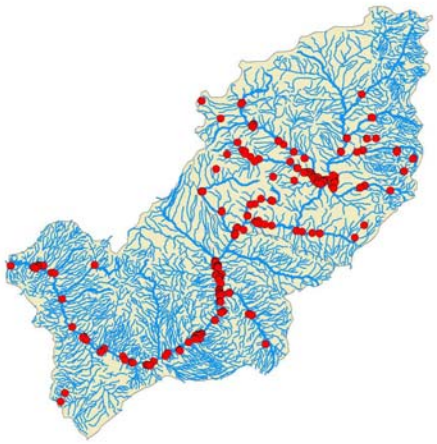
Non-indigenous species distributions

Lower Colorado River Basin Aquatic Gap Project

- 1,500,000+ fish observations
- 85,000 sites
- 1840 to 2004

Upper Gila River data

- 10,699 fish observations
- 31 fish species (19 non-indigenous)
- Primarily between 1989 to 2004
- 729 sites



Julian Olden, Jodi Whittier and Craig Paukert (unpublished)

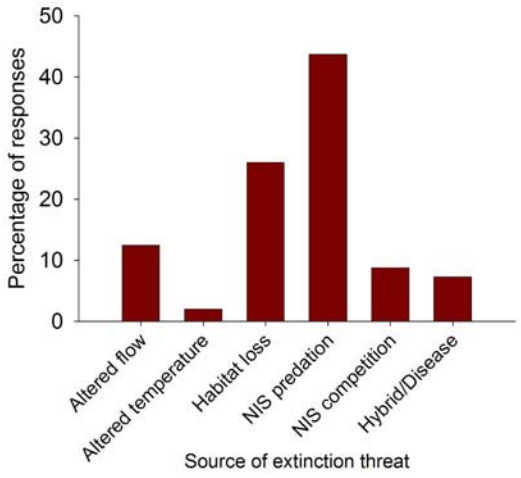
Ecological impacts

Introduction
Establishment
Integration

- Desert fishes are vulnerable to NIS because of their high degree of endemism, ecological specialization, low genetic plasticity, and limited defenses against aquatic predators
- By contrast, NIS are typically more broadly adapted, better suited to disturbed or degraded environments, more aggressive, or some combination of these
- NIS impact native fishes through competition, hybridization, predation, and spread of pathogens to which they have developed resistance in their home waters but to which native species have none (e.g., Meffe 1985, Moyle 1986, Rinne 1995, Minckley and Deacon 1991)

Ecological impacts of invasive species

- Expert survey of 20 professional fish biologists
- Participants were asked to identify the primary source of perceived risk for 28 native species
- Predation by invasive species was found to be a leading threat



Olden (2004)

Potential impact on native fishes

Benign	Potential Nuisance	Nuisance
	Bluegill (50)	Channel catfish (100) Flathead catfish (100) Smallmouth bass (94) Red shiner (94) Largemouth bass (89) Common carp (89) Green sunfish (89) Black bullhead (83) Fathead minnow (75) Mosquitofish (65) Rainbow trout (59)

Predation and competition

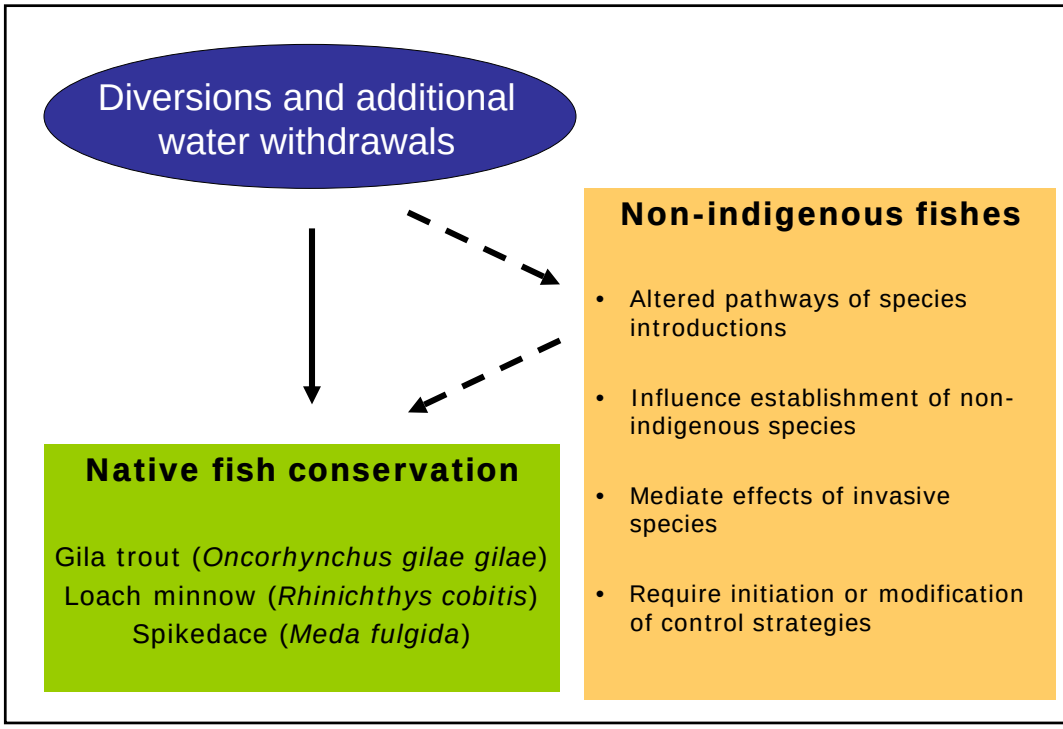
- Historically, Colorado pikeminnow (*Ptychocheilus lucius*) was the only piscivore within the native fauna
- A large number of non-indigenous species, however, are piscivorous and are capable of feeding on adults, larvae and eggs of native fishes
- Historical record of observation, research, and case study demonstrates that invasive species often eliminate or severely harm native fishes

Predation and competition

- Predation by mosquitofish (*Gambusia affinis*) and shrinking populations of the Sonoran topminnow (*Poeciliopsis occidentalis*)
- Presence of red shiner (*Cyprinella lutrensis*) and simultaneous absence of natives (inc. spikedace, *Meda fulgida*, and woundfin, *Plagopterus argentissimus*)
- Hybridization of rainbow trout (*Onchorhynchus mykiss*) with native Gila trout (*O. gilae gilae*)



What science is needed to inform the decision-making process?



1. Habitat associations and requirements of non-indigenous fishes at larval, juvenile and adult life stages
   - Explore temporal dynamics of species-environment relationships
   - Identify critical habitat needs and map key areas throughout the basin
   - Quantify similarities in resource use of native fishes
- Beyond static descriptors of habitat (e.g., depth, width) and toward a dynamic understanding of species-environment relationships
- Characterization of long-term hydrologic regime and short-term antecedent flows with respect to critical life-history stages of non-indigenous fishes

2. Life-history characterization of larval, juvenile and adult life stages of non-indigenous species
   - Provides a mechanistic basis for predicting the response of invasive species to environmental change

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LIFE-HISTORY STRATEGIES PREDICT FISH INVASIONS AND EXTIRPATIONS IN THE COLORADO RIVER BASIN

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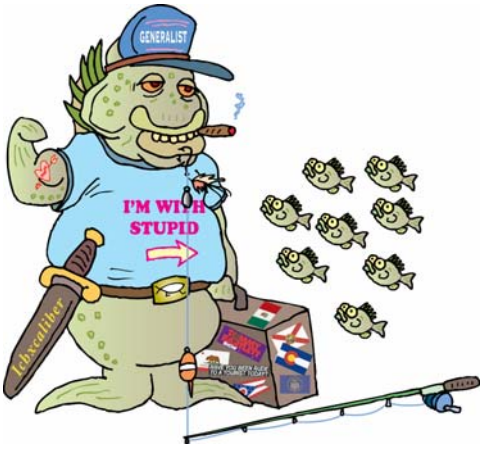
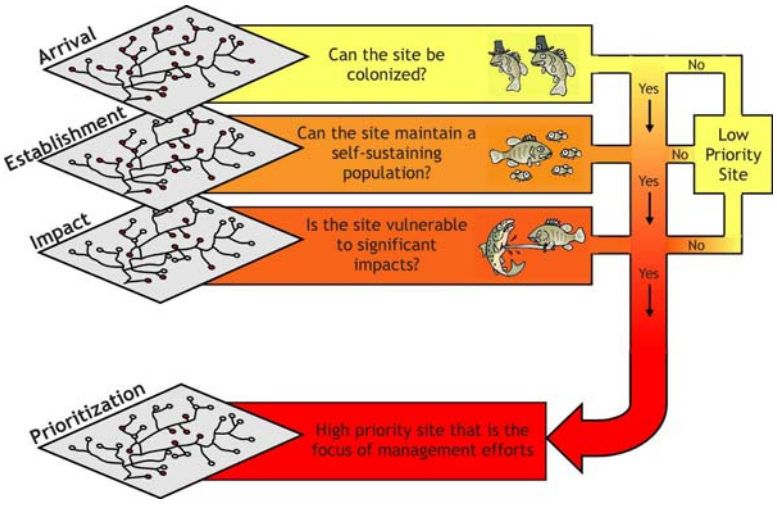
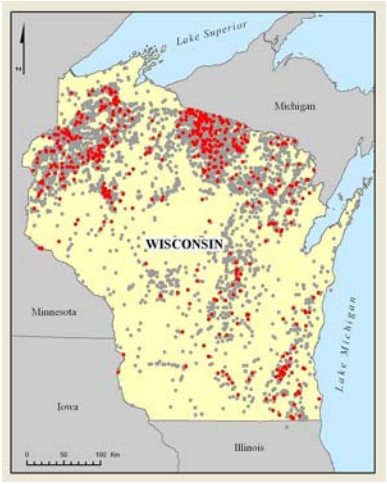


3. Forecast potential distributions of non-indigenous fishes as a function of local-, reach-, and watershed-scale descriptors of the environment



Case study:
Invasion potential of rainbow smelt

- Statistical modeling of potential distribution of rainbow smelt
- Prioritization of at-risk sites to future invasion
- Model predictions under different scenarios of environmental change
- Smallmouth bass (Vander Zanden et al. 2004)



Predicted presence

4. Identify key components of the hydrograph that discourage the spread and dominance of non-indigenous species and favor native species

Recent studies demonstrate that the success of non-indigenous fish species can be, in part, reversed if more natural flow regimes are restored

- Propst and Gido (2004) found that dam releases in the San Juan River that mimicked natural flow regimes reduced the density of high nuisance species such as red shiner, common carp and western mosquitofish
- Scoppettone et al. (2005) showed that the modification of streamflow in Kings Pool Spring (in addition to temperature and pool depth) changed the fish composition from predominantly non-native sailfin molly and mosquitofish to predominantly Ash Meadows pupfish

5. What can we learn from past experiences in the Lower Colorado River?
   - Comparisons with other southwestern rivers may lend important insight into the response of non-native fishes to flow and habitat alteration
   - E.g., patterns of diversion and non-native species proliferation in the Upper Verde River compared to the Upper Gila River (Rinne and Miller 2005)

6. Recognize invasive fish species when designing and implementing restoration activities
   - Restoration efforts aimed at native species conservation may also promote species invasions and intensify their ecological impacts

Conclusion

- We face many challenges with respect to the spread and impact of invasive fishes in the Upper Gila River
- A rich body of literature shows that altered flow regimes promote the spread of invasive fishes in the Lower Colorado River Basin
- Recent history has clearly demonstrated that once non-indigenous species invade and establish self-sustaining populations, eradication is near impossible and impacts on native communities are inevitable
- The current state of the science is such that more predictive and comprehensive risk-analysis frameworks can be developed for preventing and managing the secondary spread and ecological impact of existing species in response to future water withdrawals

COLLABORATORS

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