Aquatic Invaders of the Pacific Northwest;

Carassius auratus auratus (Common Goldfish)

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Fish 423

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(top: http://www.theatlantic.com/national/archive/2012/11/the-great-goldfish-invasion-how-an-exotic-carp-took-over-america/264420/

Bottom: http://christymcdonald.files.wordpress.com/2012/02/goldfish.jpg)

Diagnostic Information:
Common Name: Common Goldfish
Class: Actinopterygii
Order: Cypriniformes
Family: Cyprinidae
Genus: Carassius
Species: C. auratus
Subspecies: C. auratus auratus

Identification:

Goldfish can vary greatly in size, body shape, fin configuration and coloration due to intensive selective breeding. Most often in the wild, they have forward facing mouths with pharyngeal teeth, a v-shaped caudal fin. It possesses a long dorsal fin with 15 to 21 rays and a hard serrate spine at the origin of the dorsal and anal fins.

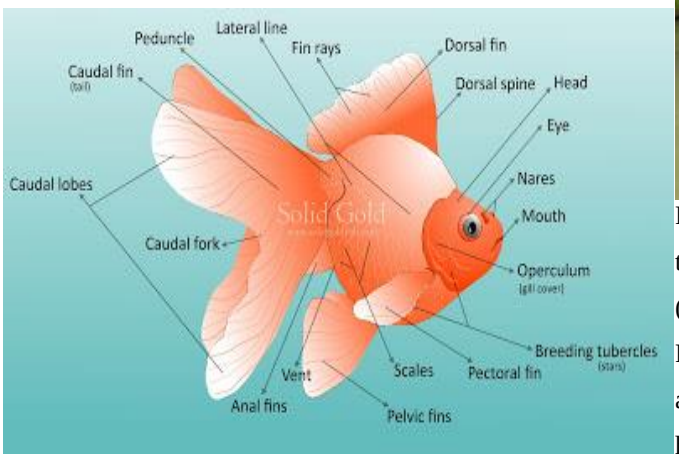


Figure 1: This diagram can be used to identify body structures mentioned throughout this paper. Although it is a drawing of a fancy goldfish, the body structures are the same for the common goldfish. Photo courtesy of Solid Gold, with Jennifer Lynx (http://www.solidgoldfish.com/2013/02/goldfish-external-anatomy.html).

Figure 2: A common goldfish, C. auratus auratus in a typical aquarium, top (http://en.wikipedia.org/wiki/Goldfish#mediaviewer/File:Goldfish3.jpg). The bottom picture depicts an alleged common carp (Cyprinus carpio) goldfish hybrid. Top picture is from wikipedia, bottom is from tnfish.org, courtesy of Melton Hill Negus (http://www.tnfish.org/PhotoGalleryFish_TWRA/FishPhotoGallery_TWRA/images/HybridCommonCarpGoldfishMeltonHillNegus_jpg.jpg).

They are often a deep orange color, making them a popular choice for aquariums, although in captivity, they can be a myriad of colors including silver, black, white, grey, red, and even a rare blue. If a goldfish in the wild is anything other than bronze/gold/orange, they could easily have originated directly from a local hobbyist's aquarium, as after a few generations, the goldfish will revert back to its wild type.

They produce a thick slime coat, which they use as a primary defense against pathogens. Goldfish tend to average 12" inches in length, although they have been known to exceed this. Different sources claim maximum recorded sizes anywhere from 19 inches to 23 inches with a maximum weight of 9.9 pounds. During their mating season, males will produce white pimple like tubercles on their operculum. Overall, female goldfish tend to be a bit smaller and rounder than male goldfish, who tend to be longer and pointier. C. auratus usually have fewer than 31 scales along the lateral line (Nico 2014). Goldfish are opportunistic feeders, meaning they will eat just about anything that can fit in their mouth, from smaller fish and insects, to plant matter, to fruit that falls into their habitat.

Life History and Basic ecology

Life cycle

Goldfish are long lived fish with a reported expectancy of 5-10 years in captivity, given proper care, although the oldest recorded goldfish was 43 years. This is often shorter in both the wild and captivity due to predation, less than ideal conditions, or improper care.

Temperature fluctuations mimicking that of spring will trigger spawning behavior in goldfish. This can be observed by white, pimple-like, breeding tubercles on the males' operculum, and aggressive chasing of the female. After the female has tired out, she will release her eggs. She may release hundreds of eggs, with some sources claiming thousands. Like all cyprinids, goldfish eggs are sticky and will adhere to substrate and plants. After the eggs are attached, the male will release milt over the eggs, fertilizing them. The eggs will then hatch in 2-5 days.

Upon hatching the goldfish fry are very vulnerable to predation at a mere 5 mm in length, so they grow rapidly for the first few weeks of their lives. For their first few days, goldfish absorb the remainder of their yolk-sac, during which time they are not free swimming, meaning they struggle to swim and will rest on the substrate or in vegetation. It may take over a year before their true coloration sets in, maintaining the metallic brown of their wild ancestors until then. Goldfish may reach sexual maturity within the year, in time for the next year's mating season, although their fecundity will continue to increase as they become larger.

Feeding Habits

Newly hatched fry will remain near the bottom of the water column before they are free swimming. During this time they are absorbing the remainder of their yolk-sac. Once free swimming, fry will forage for food in the form of microorganisms such as nematodes, plankton, and protozoans. As they become larger, they can begin to consume larger items, such as small insects and pieces of plant matter. Goldfish also seem to enjoy digging in substrate for food. This behavior can increase turbidity of the substrate is fine. As stated before, goldfish are very opportunistic omnivorous feeders, and will consume just about anything that can fit into their mouths.

Goldfish, like many other fish, rely on ambient water temperature to stabilize their own internal temperature. As a result, goldfish have faster metabolic processes in warmer waters and slower metabolic processes in cooler waters. Simply put, they will eat more and grow more in the warmer seasons than in the colder seasons. Goldfish can even go into a hibernation in the winter, allowing them to survive sub-freezing temperatures and go a substantial time without eating.

Reproductive Strategies

Before looking in detail at the reproductive patterns of goldfish, it is useful to know how to sex them. Goldfish are very difficult to sex before they are mature. Some techniques to remember when trying to sex a goldfish include looking for breeding tubercles. The white tubercles that appear during the breeding season on the rays on the pectoral fins as well as the operculum are strong indicators of a male. In rare cases a female can develop tubercles, but it is very uncommon. Another way to sex goldfish is to examine their vents. Males will usually have a concave vent, while females often have a convex vent, you should be able to see the female vent protruding from a side profile. The easiest but least reliable way to sex

goldfish is their body shape. Females typically have rounder deeper body shapes, and when viewed from the top, may have an asymmetrical abdomen.

When temperatures begin to rise in the spring, females will release pheromones into the water which encourage milt production in males and the formation of tubercles.

Figure 3: Breeding tubercles on operculum of male goldfish.

(http://aqualandpetsplus.com/Live%20Food,%20Goldfish.htm)

The exact purpose of the tubercles are unknown, however some studies of related fish suggest that they are indicators of health and dominance, so females can select a good mate. The males will start to chase the female around. They can be both relentless and aggressive in their chase, nudging the female's abdomen to try and get her to release her eggs. This behavior may persist for a week until the eggs are finally released. Once in the water column, the eggs will adhere to plants and substrate. At this point the male will release his milt, fertilizing the eggs. Although the female may release up to 1000 eggs, only a small fraction of them will survive to adulthood.

Environmental Optima and Tolerance

Goldfish are considered to be extremely hardy fish, able to survive the abuse of many novice aquarium hobbyists. While they may survive in extremely harsh conditions, they will thrive in their ideal conditions. Goldfish seem to enjoy a mildly alkaline pH of 7.2-7.6. They will do just fine in pH well outside of this range, as long as it remains stable. As with most fish, goldfish do not do well with wildly fluctuating pH. If the pH is too low, goldfish will begin to show some of the following symptoms: anorexia, excess slime, lethargy, blood streaking in fins, and death. If the pH becomes too high, these symptoms may be noticed: excess slime, gasping at the surface, and death.

Water hardness refers to the amount of dissolved minerals in the water column. Goldfish are not particular about water hardness parameters and they will do fine in hard or soft water. However, just as with pH, they don't do well in fluctuating water quality parameters, so a stable pH and hardness are ideal for goldfish health.

The temperature of the water a goldfish lives in has a direct effect on the fish's metabolism. Warmer water increases metabolic rate while cooler water lowers metabolic rate. Goldfish do best in temperatures between 20 and 22 degrees Celsius (roughly 68 - 72 degrees Fahrenheit). Just as with other parameters they can survive more extreme temperatures. It is not uncommon for goldfish to survive in a pond that has frozen over for a week. During this time, the goldfish's metabolic rate is so low that they do not eat or move, they can be considered hibernating during this time. On the flip side, goldfish can survive temperatures over 30 degrees Celsius (approaching 90 degrees Fahrenheit), although not for very long (Nico 2014). They are more tolerant of cooler water than warmer water.

Goldfish, while freshwater fish, can tolerate low levels of salinity if acclimated properly. One study, done over 72 hours indicates that goldfish can acclimate to salinity levels up to and including 10ppt with little or no adverse effects on their health. The study also saw that higher salinity levels of 15ppt-20ppt caused significant adverse effects on health and even death in some cases (Schofield 2006). To give some context, the ocean has a salinity of 35ppt. This is significant for the goldfish's potential invasive range, although more studies need to be done to evaluate long term effects of salt exposure.

Biotic Associations

Because goldfish are primarily introduced through the aquarium trade and

subsequent release, there are a plethora of potential pathogenic invaders and diseases that must be considered. One of the most common and deadly diseases in aquariums is freshwater ich. It is cause by the ectoparasite protozoan Ichthyopthirius multifiliis. It forms white nodules across the body of a fish, looking much like the breeding tubercles, but more randomly located. Each nodule is an encysted parasite. If uncontrolled, ich has a 100% mortality rate in fish. Ich has three main stages of life, the feeding stage in which the trophozoite forms a nodule on a fish and begins feeding. The tomont, in which the trophozoite falls off the fish and adheres to the substrate, preparing to divide. And finally, after dividing via binary up to 10 times, infective theronts are produced. This entire life cycle can take anywhere from 1 to 8 weeks depending on water temperature, with temperatures around 25 degrees Celsius (77 degrees Fahrenheit) being ideal.

Figure 4: A black moor (fancy) goldfish with ich disease.

(http://www.about-goldfish.com/ich-disease.html)

A common parasite found on goldfish is Lernaea Sp., a genus of copepod crustaceans commonly known as anchor worms. They mate during their last free-swimming stage of development, after which the female burrows into the flesh of a fish assuming a wormlike form, often partially hanging from the fish's body. Anchor worms can cause irritation and stress in fish, as well as breathing difficulties and general lethargy.

Figure 5: A black moor (fancy) goldfish with anchor worms.

(http://thedailydish.wordpress.com/2009/10/15/when-bad-things-happen-to-anchor-worms-good-fish-survive/)

Goldfish can often host a variety of other pathogens as well, including velvet and some fungal diseases. Unfortunately, the goldfish is often kept in very poor conditions before sold to consumers. This weakens the fish's immune system and increases the likelihood that the fish is infected with 1 or more pathogens. In addition, the goldfish is considered the beginner fish for aquarium hobbyists. They are quite often kept in very poor conditions their entire life, so on the occasion that a goldfish is released from a home aquarium, they are likely harboring a smorgasbord of pathogenic diseases.

Current Geographic Distribution

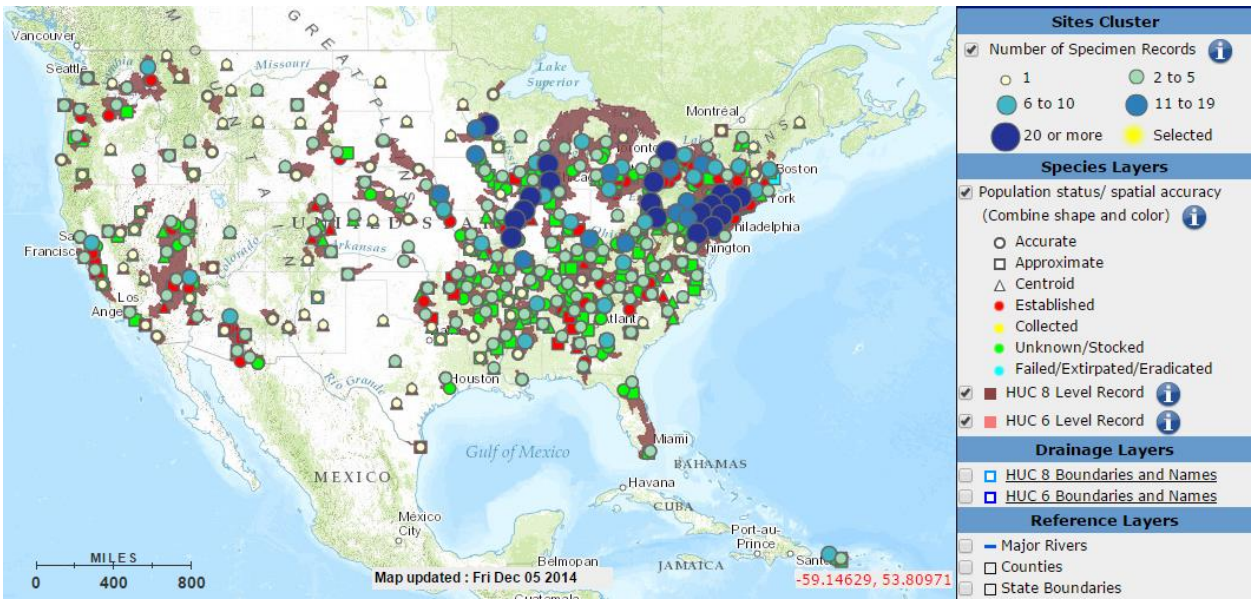
Distribution in the PNW and the United States

Common goldfish are widely distributed throughout the Unites States, largely due to their popularity in the aquarium hobby. In the case of aquariums, goldfish release is most likely intentional, with the aquarist unaware of the consequences of their actions. Goldfish are also very popular pond fish. In some cases, goldfish may escape a pond near a body of water during very heavy floods, although this is less likely than release from aquariums (Courtenay et al. 1984). They concluded that goldfish has been documented in the wild in all states except Alaska. They claimed the species as established in 16 of the lower 48 states, including

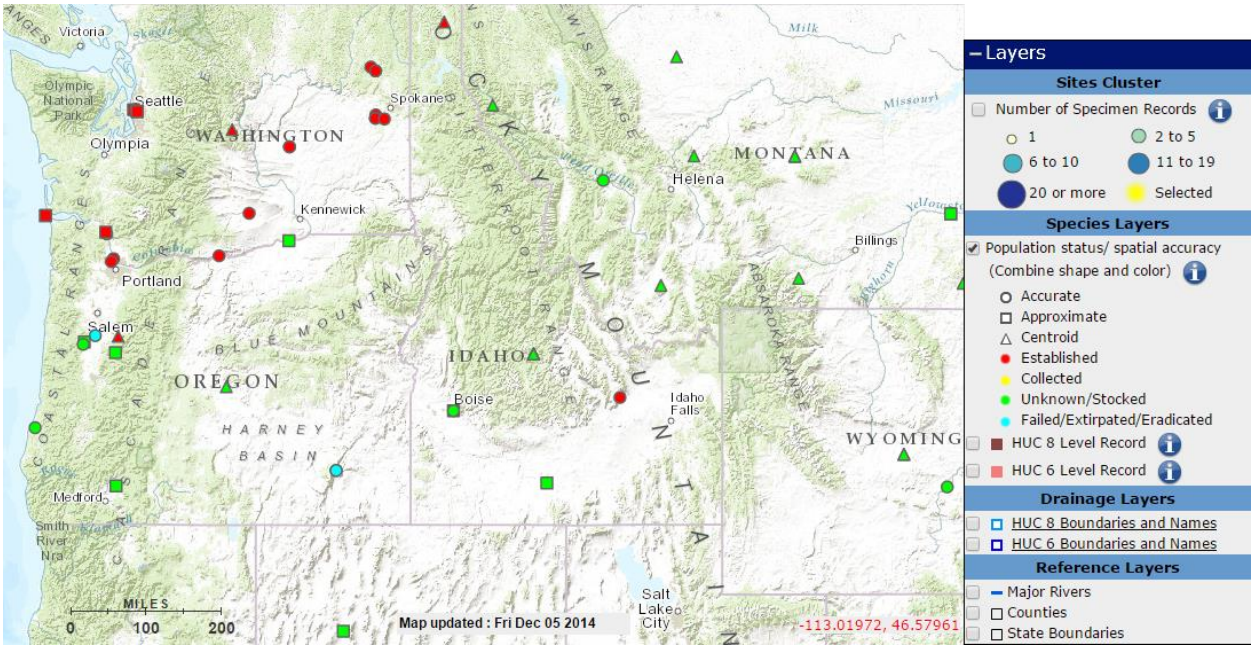
California, Delaware, Georgia, Idaho, Illinois, Indiana, Iowa, Kentucky, Maryland, Massachusetts, Michigan, Nebraska, Nevada, New Hampshire, New York, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Virginia, Washington, and Wisconsin. They also listed it as possibly established in 17 additional states: Alabama, Arizona, Arkansas, Colorado, Connecticut, Kansas, Louisiana, Minnesota, Mississippi, Missouri, Montana, New Jersey, New Mexico, North Carolina, North Dakota, Oregon, and Wyoming.

Goldfish has been recorded from Florida, Maine, Utah, Vermont, and West Virginia, however, there is no available data indicating the presence of established populations. Countryman (1975) listed it as "naturalized" in Vermont, which suggests the presence of reproducing populations.

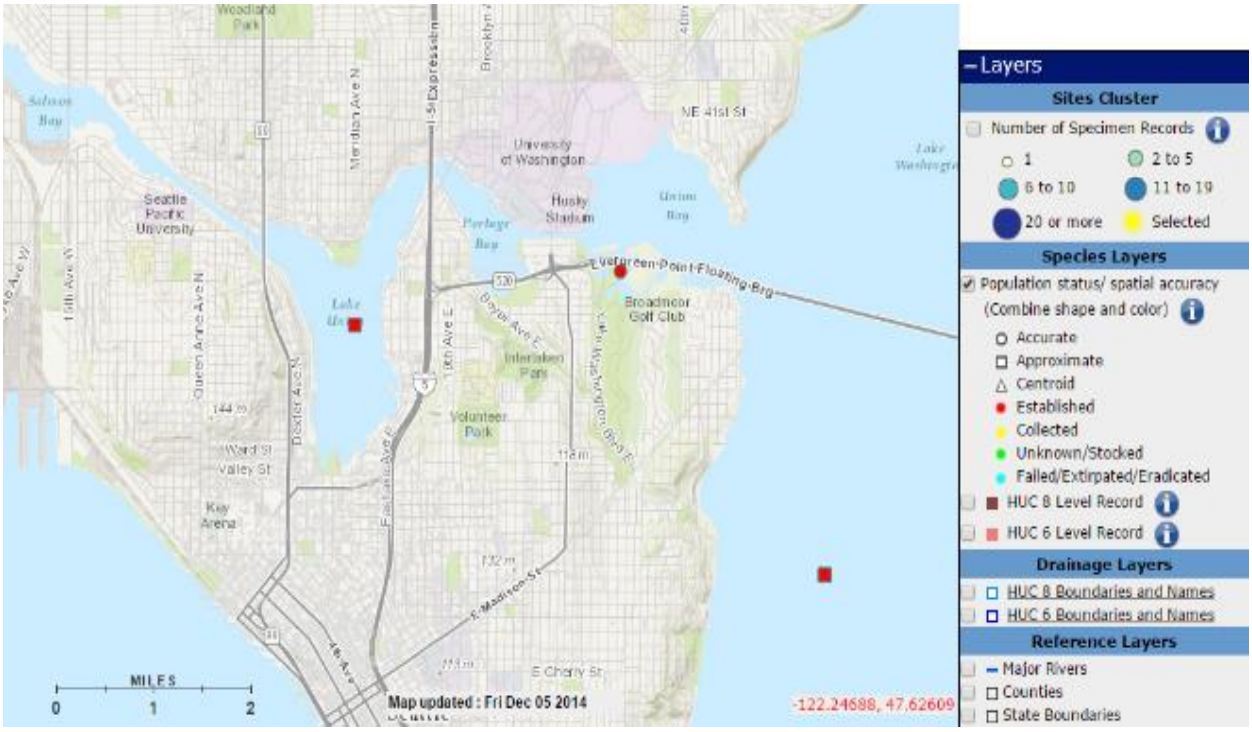
Figure 6 shows the overall distribution as of today of wild goldfish in the United States. Each subsequent map zooms in closer to the University of Washington.



Map 1: This map, courtesy of USGS, indicates the number of recorded wild goldfish across the USA. The highest numbers of recorded specimens are in the Northeast of the country.



Map 2: This map, courtesy of USGS, is a highlight of the Pacific Northwest. It does not show the number of recorded specimens but instead indicates if a population is established. The different shapes indicate level of certainty, with circles being confirmed. Red indicates an established population.



Map 3: This map, courtesy of USGS, is a super close up on Seattle, specifically right near the University of Washington. It clearly shows 1 confirmed established population in Union Bay, with 2 approximate established populations in Lake Union and Lake Washington.

According to USGS, goldfish populations have been established in Lake Union and Lake Washington since around 1936.

History of Invasiveness

According to Courtenay and Stauffer (1990), goldfish may have been first released in the United States as early as the late 1600s. They suggest that these early introductions were a result of intentional releases by settlers wanting to improve the local fish fauna. During the late 1800s, the U.S. Fish Commission raised goldfish and was responsible for distributing it across the country for the purpose of "meeting the demand for fish for aquaria, fountains, and ornamental lakes" (McDonald 1886, 1893). In the early 1900s goldfish were introduced to Wisconsin via a fish exchange program with the Nebraska Fish Commission, according to Johnson and Becker (1980). Shipments of goldfish were being made to San Francisco as early as 1867. More recent introductions of goldfish in the United States were likely the result of escapes from hatcheries and ponds, escapes and releases of baitfish, and aquarium releases (Knapp 1953; Courtenay and Hensley 1979; Courtenay et al. 1984; Pflieger 1997).

Invasion Process

Pathways, vectors and routes of introduction

For the most part, goldfish are introduced by either misinformed or uninformed aquarium hobbyists. Many people get goldfish as gifts, or they win them at the fair. At this point they are excited for their new fishy friend, and they try to love them and give them the right home. Those that succeed will go on to notice that their once little friend is not so small anymore. Recall that goldfish, given the proper care, can reach sizes of 12". Many find that they longer have the space for their beloved pet, some people may decide to move and can't bring it with them. Others may just not like their goldfish anymore. Whatever the case, it comes down to a decision on the hobbyist's part. Do they murder their pet that they cared for and loved for all those years, do they find it a happy new home, or do they release it into the wild, from whence it allegedly came? For many, they can't bring themselves to euthanize their pet, and they can't find a suitable home, so they opt for the release of their pet.

Now, most goldfish you find in aquariums weren't born there. They were most likely bred by a breeder or came from an aquaculture facility and shipped off to a local distributor. They may spend weeks or even months in the care of the distributor, often in cramped aquariums with poor conditions. All of this is very stressful and the weaker fish may die. Eventually a novice aquarist will come along and decide to adopt five of those sad looking goldfish. Most likely of those five, very few survive.

These bottlenecks impart a very high selecting force on goldfish for only the very best survivors. The poor care of goldfish in many large distributor facilities, coupled with the goldfish's stigma as the ultimate beginner fish make the selection on goldfish significantly higher than most other common aquarium fish.

Figure 9: Overstocked goldfish tank from China, where many goldfish are bred to be shipped into the United States (http://www.aquarticles.com/images/China%201c/p16%20Goldfish.jpg)

Besides intentional release from aquariums, goldfish may also escape from breeding facilities. Many breeding facilities are near bodies of water with acceptable parameters for the husbandry of goldfish (so that they can utilize this water as a resource). However, during the heavy rains this body of water may overflow and flood the facility. In the case of a flood, goldfish may escape into the wild. Some individuals may also stock goldfish as a feeder fish in small lakes.

Another method by which goldfish are unintentionally introduced to bodies of water is

through their use as bait fish. Since goldfish are many sizes, cheap, and colorful, they make for decent baitfish, or at least they would if they didn't establish so easily. In any case, some states have laws in place which prohibit the use of goldfish as bait.

Factors Influencing Establishment and Spread

The goldfish has many attributes that make it an outstanding specimen for establishment. First and foremost is the goldfish's high range of environmental tolerance, giving it a very large portion of the globe that it could establish in. The goldfish can handle temperatures from below freezing to over 30 degrees Celsius. It can survive salinities from 0 ppt up to 10 ppt (Schofield 2006). It can tolerate a pH range of 6.2 to 8.5. In addition to its wide range of tolerances, the goldfish also has a very wide ranging diet. Since they are opportunistic omnivorous fish they will, for the most part, eat anything that can fit into their mouths, including but not limited to smaller fish, plant matter, decaying matter, and insects. These fish can also live for a multitude of years, up to 30 years, although this is quite rare. Their (relatively) long life means that they will have many chances to breed and establish in new territories. Goldfish, however, are easily predated upon, since they are not known for being particularly fast.

Potential Ecological and Economic Impacts

In the aquarium trade, it is well known that goldfish are very messy fish. What this means is that goldfish produce a disproportionate amount of waste compared to their total mass. If a large population of goldfish establishes in a small body of water, the waste products (ammonia) should be monitored for stability. This is a non-issue in larger bodies of water. The main threat that goldfish really pose is that of competition.

As previously stated, goldfish are highly opportunistic omnivorous feeders, and they eat a lot. They may provide enough pressure on a small food source to have adverse effects on local fauna. In addition to competing for food, a digging behavior has also been noted in goldfish, and many sources claim they tend to dig up plants in aquaria. If that behavior persists in the wild, then they may pose a threat to shallow rooted plants. Through experiments, and observations Richardson et al. (1995) found that the goldfish is a benthic herbivore whose behavior often results in visible increases in turbidity and decreases in aquatic vegetation. However, Laird and Page (1996) claimed that goldfish in Illinois appear unable to compete with native fish, and can only establish in severely disturbed areas. According to Moyle (1976) large populations of this species can greatly disturb sport fish habitats.

Goldfish may also play a role as a food source for local predators. However, studies have suggested that goldfish may contain thiaminase, an enzyme which breaks down thiamin. Thiamin, better known as vitamin B1, is a colorless and water soluble chemical that helps to convert carbohydrates into glucose (Anglesea and Jackson 1985). It is particularly important for the correct functioning of the nervous system. A lack of Vitamin B1 is called a Thiamine Deficiency Syndrome. Many predatory invertebrates such as eels are very prone to Thiamine Deficiency Syndrome, so in consuming goldfish (which contain thiaminase), they are actually at a serious risk.

The offspring of salmon from the Baltic Sea, which apparently feed mostly on thiaminase rich herring and relatively little food that contains high levels of Vitamin B1, were found to suffer from a condition called Reproduction Disorder M74 (Wistbacka et al. 2002). This was later identified as being simply one particular form of Thiamine Deficiency Syndrome. The eggs produced by adult salmon were provided with very little thiamin, and the fry that emerged almost all died soon after hatching. Comparable problems have been found among salmonids in the Great Lakes of North America, and this has been hypothesized to be related to a diet containing a large proportion of alewives, another type of thiaminase rich fish. Considering that Goldfish are also a thiaminase rich food, if a predatory fish in the pacific northwest, such as salmon, were to become dependent on a large, established invasive goldfish population, we may end up with a similar problem. Fortunately, in most cases, goldfish remain in relatively small

populations across North America, especially in the Pacific Northwest, so their relative threat remains low.

Management strategies and control methods

Most of the management strategies for goldfish across North America are related to use as baitfish, that is, they strictly prohibit their use as baitfish. However, there are few strategies in place currently. In Ney York and Pennsylvania, it is illegal to use or possess goldfish as baitfish. In Minnesota, goldfish are a regulated invasive species, making introduction of the species without a permit illegal. In Wisconsin, goldfish are a restricted invasive species.

As of yet, there is no known biological control for goldfish. Physical removal, however, is an option, especially in small ponds (Morgan et al 2005). Yamamoto et al. (2006) claims that physical lowering the water level has a significant negative impact on cyprinid spawning abilities. In Lake Biwa, in japan, cyprinid eggs were noticeably reduced when water levels were lowered by 30 cm. Even a 10 cm reduction can significantly reduce spawning areas preferred by cyprinids (Yamamoto et al. 2006). Clearwater et al (2008) claims that liming could be a potential control method for goldfish.

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Current research and management efforts

As of right now, most states do not consider goldfish a pest. As such, the only management efforts in the USA are restrictions on use as bait fish in some states, while some other states regulate stocking and intentional introductions. There is no current regulation on the possession or purchase of goldfish for aquaria. There are currently, to the best of our knowledge, no attempts to physically remove established populations of goldfish, as they pose no immediate threat (Nico 2014).