Alewife (*Alosa pseudoharengus*)
Ecological Risk Screening Summary

Web Version—08/18/2014

Photo: D. Raver, USFWS.

1 Native Range, and Status in the United States

Native Range
From Whitehead (1985):

"North America: Atlantic coast from the Gulf of St. Lawrence and Nova Scotia to North Carolina and in streams and rivers."

Status in the United States
From Fuller et al. (2014):

"Established in many states and throughout the Great Lakes. Introduction to the Youghiogheny River was unsuccessful (Hendricks et al. 1979)."

"Alewife were introduced into Colorado (Minckley 1973); Georgia (Dahlberg and Scott 1971); Lake Michigan, Illinois (Miller 1957, Smith 1979, Phillips et al. 1982, Emery 1985); Lake Michigan (Miller 1957, Phillips et al. 1982, Emery 1985), Indiana Dunes National Lakeshore (Tilmant 1999), Bass Lake (INDNR) Indiana; Kentucky (Burr and Page 1986, Burr and Warren 1986); Maine (Smith 1985); Massachusetts (Hartel 1992); the Great Lakes (Miller 1957, Eddy and Underhill 1974, Phillips et al. 1982, Emery 1985, Smith 1985), Isle Royale National Park, Pictured Rocks National Lakeshore, and Sleeping Bear Dunes National Lakeshore (Tilmant 1999) and Lake St. Clair (Cudmore-Vokey and Crossman 2000) Michigan ; Lake Superior, Minnesota (Miller 1957, Eddy and Underhill 1974, Phillips et al. 1982, Emery 1985); Nebraska (Morris et al. 1974, Bouc 1987); New Hampshire (Smith 1985); Adirondack lakes (Smith 1985), Otsego Lake in 1988 (T. Sinnott, personal communication), Lake Erie (Miller 1957, Eddy and Underhill 1974, Emery 1985, Smith 1985), lakes in the headwaters of Black River, the St. Lawrence Seaway, and Saratoga Lake (Smith 1970), Otisco Lake (Kelly 2001), and possibly Lake Ontario (Smith 1970, Smith 1985), New York; Lake Erie and Conneaut, Ohio (Miller 1957, Emery 1985); Lake Erie (Miller 1957, Eddy and Underhill 1974, Emery 1985), Youghiogheny River (Hendricks et al. 1979), and Colyer Lake in Centre County (Denoncourt et al. 1975), Delaware Water Gap National Recreation Area (Tilmant 1999), Pennsylvania; Lake Moultrie, Lake Marion, Congaree River, and Wateree River, South Carolina (Rohde et al. 2009); Dale Hollow and Watauga Reservoirs, Tennessee (Etnier and Starnes 1993, W. Pollock, personal communication); Lake St. Catherine and Lake Champlain, Vermont (Hauser 1998, Marsden and Hauser 2009); several reservoirs in Virginia (Hocutt et al. 1986, Jenkins and Burkhead 1994); Bluestone Reservoir, New drainage, West Virginia (Hocutt et al. 1986, Stauffer et al. 1995, Jenkins and Burkhead 1994); and lakes Michigan and Superior, Kangaroo Lake, Pigeon River, Pigeon Lake, East Twin River, Sheboygan River, Green Bay, St. Louis River estuary, Sauk Creek, and Milwaukee River, Wisconsin (Miller 1957, Phillips et al. 1982, Becker 1983, Emery 1985, Czypinski et al. 2002)."

"Collected from Lake Superior at Thunder Bay, Ontario, Canada (USGS Lake Superior Biological Station)."

From Whitehead (1985):

"Also occurs in Lake Seneca and Cayuga."

Means of Introductions in the United States

From Fuller et al. (2014):

"There is apparently disagreement concerning the native status of alewife in Lake Ontario. Miller (1957) and Smith (1970) point out the first record from Lake Ontario was in 1873. Smith (1970) is of the opinion that it was introduced into the lake. Although Smith (1970) brings up the possibility that alewife were introduced into Lake Ontario with American shad stockings in the 1880s, he discounts this possibility in favor of the hypothesis that they reached the lake via the Erie Canal from the Hudson River. He contends that alewife were only able to invade the lake after the decline of predators such as lake trout and Atlantic salmon in the 1860s. Other authors believe, this species was probably native to Lake Ontario (Lee et al. 1980 et seq.) and spread through the Great Lakes via the Welland Canal (Lee et al. 1980 et seq.). The species was first reported from Lake Erie in 1931, Lake Huron in 1933, Lake Michigan in 1949, and Lake Superior in 1954. The alewife was intentionally stocked in inland waters. The population in the New River, West Virginia, resulted from stockings in Claytor Lake, New River, Virginia (Jenkins and Burkhead 1994). The recently discovered population in Lake St. Catherine, Vermont, is likely a result of an illegal stocking (Good, personal communication). Lakes in the

Adirondack Mountains and Otsego Lake, New York were illegally stocked with alewife for forage (Smith 1985, Sinnott, personal communication, D. Warner, personal communication).”

Remarks

From Fuller et al. (2014):

“Although there is a report of two small alewives taken from the Colorado River, Texas (Bean 1882), we believe this record is in error. Bean (1882) reported that the specimens were sent to Professor Baird at the National Museum. However, a query of the museum's holdings did not return these specimens. We believe the fish are more likely either misidentified *A. chrysochloris* or *A. sapidissima*. *Alosa sapidissima* were stocked in the Colorado River in 1874 (Bean 1882).”

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

From ITIS (2011):

“Kingdom Animalia
Subkingdom Bilateria
Infrakingdom Deuterostomia
Phylum Chordata
Subphylum Vertebrata
Infraphylum Gnathostomata
Superclass Osteichthyes
Class Actinopterygii
Subclass Neopterygii
Infraclass Teleostei
Superorder Clupeomorpha
Order Clupeiformes
Suborder Clupeoidei
Family Clupeidae
Subfamily Alosinae
Genus Alosa
Species Alosa pseudoharengus (Wilson, 1811)

Taxonomic Status: Valid.”

Size, Weight, and Age Range

From Whitehead (1985):

"Maturity: Lm ?, range 11 - ? cm; Max length : 40.0 cm SL male/unsexed; (Robins and Ray 1986); common length : 30.0 cm SL male/unsexed; (Robins and Ray 1986); max. published weight: 200.00 g (Robins and Ray 1986); max. reported age: 9 years (Altman and Dittmer 1962)."

Environment

From Whitehead (1985):

"Marine; freshwater; brackish; pelagic-neritic; anadromous (Riede 2004); depth range 5 - 145 m (Jones et al. 1978), usually 56 - 110 m (Scott and Scott 1988)."

Climate/Range

From Whitehead (1985):

"Temperate; 55°N - 34°N, 93°W - 53°W."

Distribution Outside the United States

Native

From Whitehead (1985):

"North America: Atlantic coast from the Gulf of St. Lawrence and Nova Scotia to North Carolina and in streams and rivers."

Introduced

From Fuller et al. (2014):

"Collected from Lake Superior at Thunder Bay, Ontario, Canada (USGS Lake Superior Biological Station)."

Also present in Canadian waters of the other Great Lakes.

Means of Introduction Outside the United States

From Fuller et al. (2014):

"Although Smith (1970) brings up the possibility that alewife were introduced into Lake Ontario with American shad stockings in the 1880s, he discounts this possibility in favor of the hypothesis that they reached the lake via the Erie Canal from the Hudson River. He contends that alewife were only able to invade the lake after the decline of predators such as lake trout and Atlantic salmon in the 1860s. Other authors believe, this species was probably native to Lake Ontario (Lee et al. 1980 et seq.) and spread through the Great Lakes via the Welland Canal (Lee et al. 1980 et seq.). The species was first reported from Lake Erie in 1931, Lake Huron in 1933, Lake Michigan in 1949, and Lake Superior in 1954."

Short description

From Whitehead (1985):

"Dorsal spines (total): 0; Anal spines: 0. Moderately compressed, belly with a distinct keel of scutes. Lower jaw rising steeply within mouth; minute teeth present at front of jaws (disappearing with age). Lower gill rakers increasing with age. A dark spot on shoulder. Distinguished from *A. aestivalis* by its silvery peritoneum; eye larger than snout length; back greyish green on capture."

Biology

From Whitehead (1985):

"Movement of schooling adults apparently restricted to coastal areas proximal to natal estuaries (Jones et al. 1978). They migrate up rivers and even small streams to spawn in lakes and quiet stretches of rivers, then return to sea shortly after spawning (Jones et al. 1978); landlocked populations also ascend affluent rivers and streams. Larvae remain in vicinity of spawning grounds, forming schools at sizes less than 10 mm TL, within one to two weeks after hatching (Jones et al. 1978), then descend in summer and autumn or even as late as November or December. Feed on shrimps and small fishes; the young on diatoms, copepods and ostracods while in rivers […] Overfishing, pollution and impassable dams cause the decline of stocks (Bigelow et al. 1963)."

Human uses

From Whitehead (1985):

"Fisheries: commercial; bait: occasionally"

"Utilized fresh, dried or salted, smoked and frozen; eaten fried (Frimodt 1995). Also used for crab and lobster bait and sometimes for pet food (Frimodt 1995)."

Diseases

From Whitehead (1985):

"Parasites found are Acanthocephala, cestodes, trematodes and copepods."

There are no known OIE-reportable diseases listed for this species.

Threat to humans

Harmless.

3 Impacts of Introductions

From Fuller et al. (2014):

"Presence of the alewife could restructure a lake's food web, leaving less food for native species (USEPA 2008). Disappearance of native planktivorous salmonids, such as whitefish, in the Great Lakes has been attributed in part to the introduction of alewife, which reduced zooplankton populations (Crowder and Binkowski 1983, Todd 1986, Page and Laird 1993). Crowder (1984) speculated that a cisco native to Lake Michigan, the bloater *Coregonus hoyi*, evolved fewer and shorter gill rakers, and shifted to benthic habitat and diet as a result of competition with alewifes. Smith (1970) attributed the extermination of the lake herring and decline of chub species in the Great Lakes to the alewife. Smith also talks about the various interrelated changes that took place in each of the Great Lakes as alewife abundance increased. Christie (1972), on the other hand, argues that the alewife was not responsible for these changes. The alewife is the dominant fish in Lake Michigan. It accounts for 70–90% of the fish weight (Becker 1983). Alewife has recently become the dominant prey item for double-crested cormorants in Lake Champlain (DeBruyne et al. 2012). Additionally, alewife (both age-0 and adults) show significant spatial overlap with age-0 rainbow smelt (*Osmerus mordax*) in Lake Champlain, which could alter population dynamics of both species through competition (between age-0 alewife and smelt) or predation (by adult alewife on age-0 of both species) and limit the availability of these forage fish to larger predators such as lake trout (*Salvelinus namaycush*) and Atlantic salmon (*Salmo salar*) (Simonin et al. 2012)."

"Alewife is a very important species in the history of biological invasions in the Great Lakes. Periodic large-scale die-offs littered the beaches of the Great Lakes with rotting fish in the 1960's. Such die-offs can pose both a nuisance and a health hazard (Becker 1983). Prompted by calls for alewife management, Pacific salmonids were introduced to both control alewife populations and utilize alewife as a food source for sport fisheries."

From GISD (2011):

"In the Laurentian Great Lakes, the alewife invasion has been associated with declines in abundance of emerald shiner (*Notropis atherinoides*), yellow perch (*Perca flavescens*), deepwater sculpin (*Myoxocephalus thompsoni*), and burbot (*Lota lota*). Alewives are suspected of interfering with reproduction of these fishes, most likely by preying upon the pelagic fry (Chuck Madenjian pers.comm. 2004)."

"Multiple impacts have been reported by the Vermont Department of Environmental Conservation (VTDEC 2002). Alewives are extremely efficient feeders on zooplankton. They feed selectively on the larger species and the larger individuals within a species, causing drastic alterations in zooplankton size, abundance and community structure. *A. pseudoharengus* out-compete other fish species for food. Alewives compete directly for zooplankton with other planktivorous fish, including yellow perch (*Perca flavescens*) and rainbow smelt (*Osmerus mordax*), and with the young of many piscivorous species, such as bass, which are dependent on zooplankton during the early parts of their lives. *A. pseudoharengus* feed on the eggs and larvae of other fish. Predation on yellow perch and lake trout (*Salvelinus namaycush*) larvae appears to be a significant source of mortality in those species. *A. pseudoharengus* are the cause of major reproductive failures in landlocked Atlantic salmon (*Salmo salar*) and lake trout populations."

"*A. pseudoharengus* undergoes periodic mass mortalities. The large numbers of alewives that die in these events wash up on beaches, causing foul odors and public health concerns. Any predator fish that utilises *A. pseudoharengus* populations as a main source of food will have difficulty finding enough to eat after an alewife mass mortality. This results in poor growth rates and declines in game fish. Land-locked alewives are high in thiaminase and Atlantic salmon and lake trout that eat mainly alewives produce thiamine deficient eggs which results in high mortality of fry from a syndrome linked to thiamine deficiency (O'Gorman and Stewart 1999)."

"Otsego Lake (United States (USA))

Modification of natural benthic communities: Changes in Otsego Lake also include an increase in lake trout (*Salvelinus namycush*) and a decline in whitefish (*Coregonus clupeaformis*) and cisco numbers. The authors state that these changes have occurred in spite of significant efforts to reduce non-point source nutrient loading to the lake.
Modification of successional patterns: Changes have taken place in Otsego Lake from the 1930s to present, at the trophic level. Prior to the introduction of the alewife in 1986 cisco (*Coregonus artedi*) was the dominant planktivore. Different patterns are observed in the pelagic flora and fauna under these two dominant planktivore populations. When cisco were the primary planktivores, cladoceran size and biomass was significantly greater in the epilimnion (primarily *Daphnia pulex*) than in the hypolimnion (primarily *Bosmina coregoni*). Phytoplankton were dominated by net and large [nanoplankton] (>0.03mm), with cyanobacteria uncommon until late summer. Since alewife have dominated, *Daphnia* have become rare. Mean cladoceran size in the epilimnion and hypolimnion (essentially all *Bosmina*) is much more uniform and reduced from prior size distributions. Phytoplankton abundance and mean summer chlorophyll has increased. The dominant algae are now smaller [nanoplankton] (<0.03mm) and cyanobacteria."

"Great Lakes (USA) (United States (USA))

Predation: Predates on the larval stages of *Salvelinus namaycush* and also causes diet mediated thiamine deficiency in larval stages of the lake trout causing death."

From O'Gorman (2014):

"Introduction of *A. pseudoharengus* is unlikely without a concerted effort unless the receiving waterbody is in a watershed where *A. pseudoharengus* are already established. *A. pseudoharengus* can move within a watershed through rivers and canals, even through canals with navigation locks. There is a large body of literature on the adverse affects of introducing alewife to freshwater ecosystems (O'Gorman and Stewart 1999, Madenjian et al. 2008, O'Gorman et al. in press) so natural resource management agencies are vigilant against further introductions. The greatest risk for introduction appears to be from illicit releases by individuals seeking to "improve" fishing, followed by accidental introduction by release of *A. pseudoharengus*, illegally used for live bait. *A. pseudoharengus* are somewhat fragile and are therefore not used in the aquarium trade or transported live for human consumption."

"Establishment of alewife populations in land-locked waterbodies has had both positive and negative economic impacts. The negative impact most noticeable to the general public has been the periodic die-offs of large numbers of fish. As early as 1892, residents of Burlington, Canada, on Lake Ontario, were complaining of the costs of removing the smelly, dead *A. pseudoharengus* that washed ashore in summer (Pritchard 1929). In 1967, a massive die-off of *A. pseudoharengus* in Lake Michigan (the fifth largest lake in the world) resulted in an estimated loss in excess of 100 million dollars to industry, municipalities, and businesses dependent on recreation (Greenwood 1970). Other less visible but no less important negative economic impacts include harmful effects on other fishes important to recreational and commercial fisheries."

"When *A. pseudoharengus* become established in a waterbody they alter the size and species composition of the zooplankton community by size-selective predation (Brooks and Dodson 1965, Wells 1970, Warshaw 1972, Johannsson 2003). Kelso and Ney (1983) noted that the high foraging efficiency of *A. pseudoharengus* on zooplankton may result in trophic competition with juvenile fishes in the littoral zone of a reservoir. Depression of zooplankton can reduce grazing of phytoplankton resulting in decreased water clarity."

"Alewife populations in landlocked waterbodies negatively impact biodiversity in three ways. First by size-selective predation on zooplankton they can eliminate the largest species and shift dominance to the smallest species (Brooks and Dodson 1965, Wells 1970, Warshaw 1972, Johannsson 2003). Second, by preying on pelagic larvae of native fishes with no evolutionary exposure to *A. pseudoharengus*, they can sharply curtail recruitment, depressing populations of native fishes (Madenjian et al. 2008, O'Gorman et al. in press). Third, by causing a thiamine deficiency among some salmonines that eat mainly *A. pseudoharengus*, they can lower reproductive success of ecologically and economically important top predators. *A. pseudoharengus* contain high concentrations of thiaminase, an enzyme that breaks down thiamine (Gnaedinger 1964). Female salmonines that eat mostly *A. pseudoharengus* can produce thiamine-deficient eggs (Marcquenski 1996, Brown et al. 1998, 2005) and the young that emerge from those eggs develop Early Mortality Syndrome (EMS), a syndrome characterized by abnormal behaviour, physical abnormalities, and death (McDonald et al. 1998). EMS is thought to be one of the major impediments to restoring the native lake trout *Salvelinus namaycush* to many areas of the Laurentian Great Lakes (Madenjian et al. 2008). The final elimination of the native, land-locked Atlantic salmon *Salmo salar* from Lake Ontario in the late 1800s, soon after alewife proliferated, may well have been due to thiaminase-induced thiamine deficiency (Ketola et al. 2000, Madenjian et al. 2008)."

4 Global Distribution

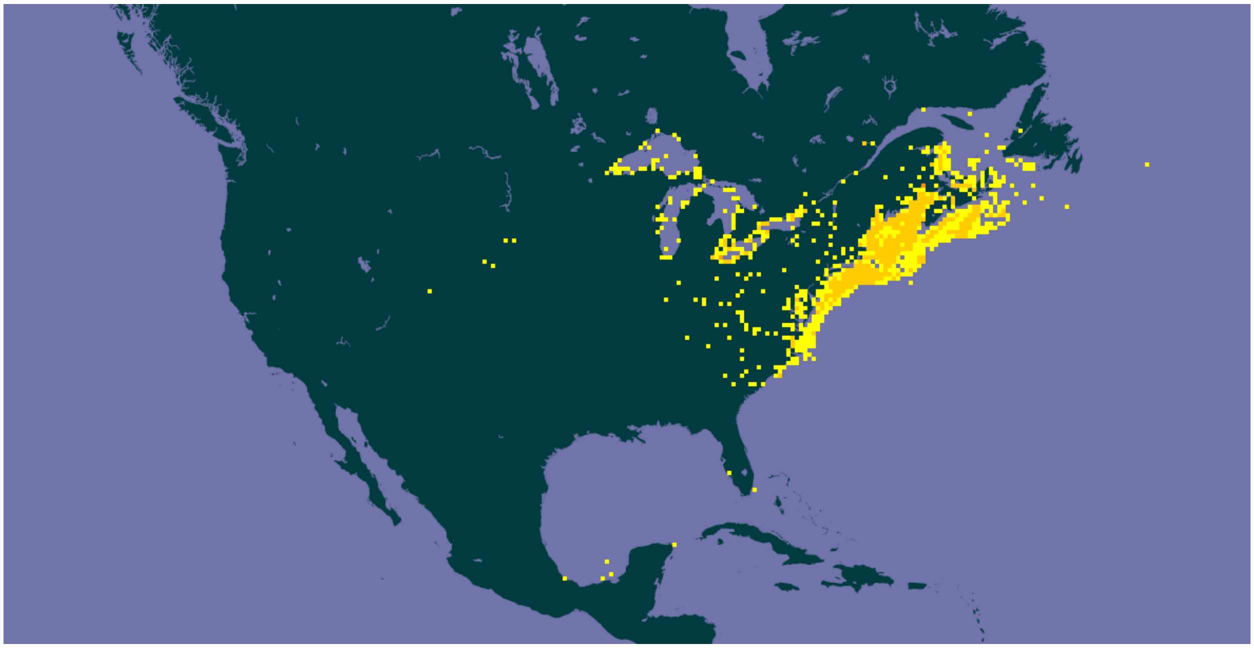

Figure 1. Global distribution of *Alosa pseudoharengus*. Locations in Kazakhstan were not included due to incorrect positioning. Map from GBIF (2014).

5 Distribution within the United States

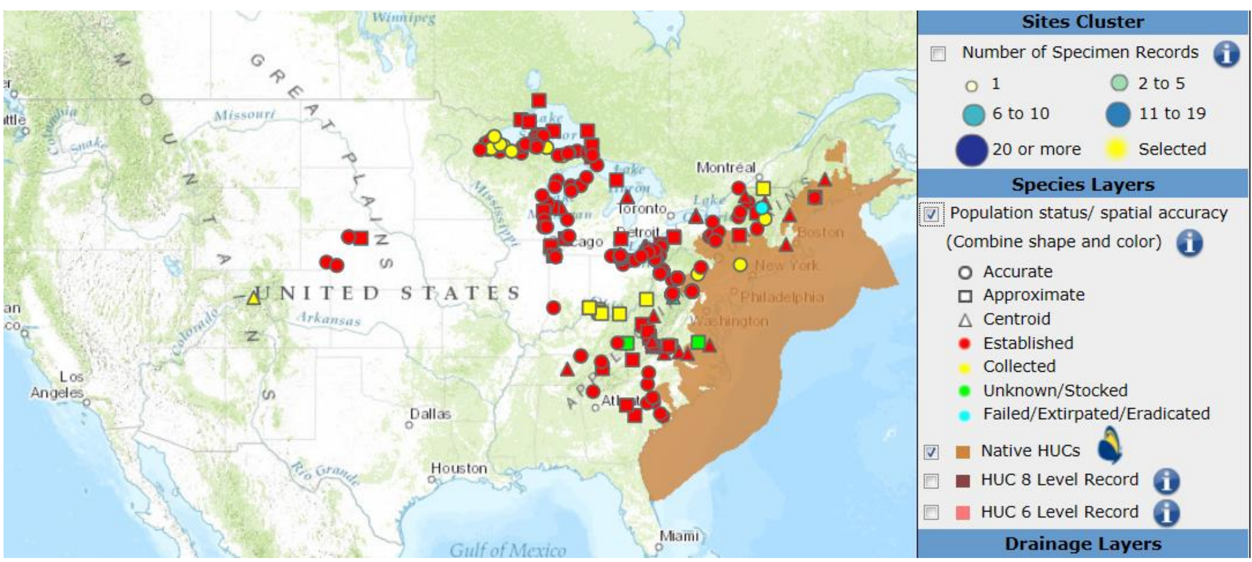

Figure 2. Distribution of *Alosa pseudoharengus* in the U.S. Map from Fuller et al. (2014).

6 CLIMATCH

Summary of Climate Matching Analysis

The climate match (Australian Bureau of Rural Sciences 2008; 16 climate variables; Euclidean Distance) was high throughout most of the contiguous U.S. Low scores occurred only along the West Coast and the extreme desert southwest. Climate 6 match indicated that the contiguous U.S. has a high climate match. The range for a high climate match is 0.103 and greater; climate match of *Alosa pseudoharengus* is 0.740.

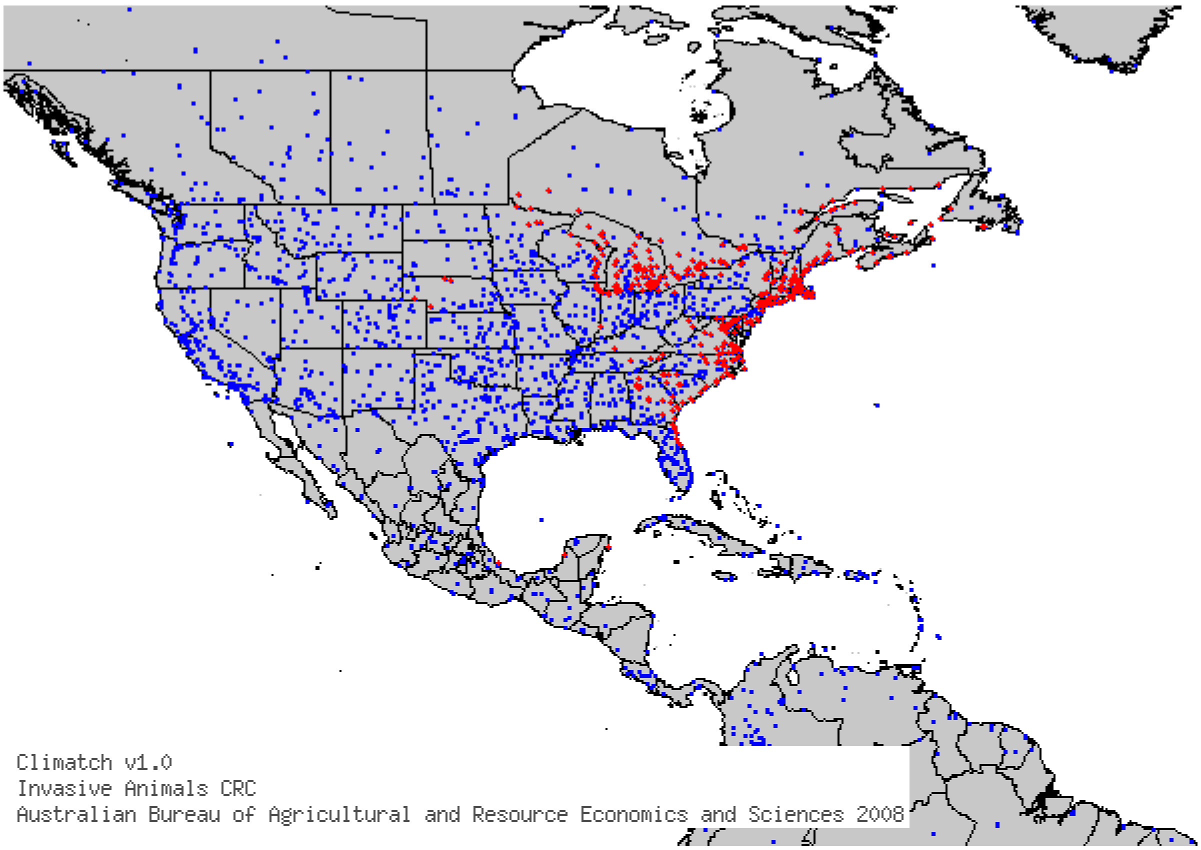

Figure 3. CLIMATCH (Australian Bureau of Rural Sciences 2008) source map showing weather stations selected as source locations (red) and non-source locations (blue) for *Alosa pseudoharengus* climate matching. Source locations from GBIF (2014) and Fuller et al. (2014).

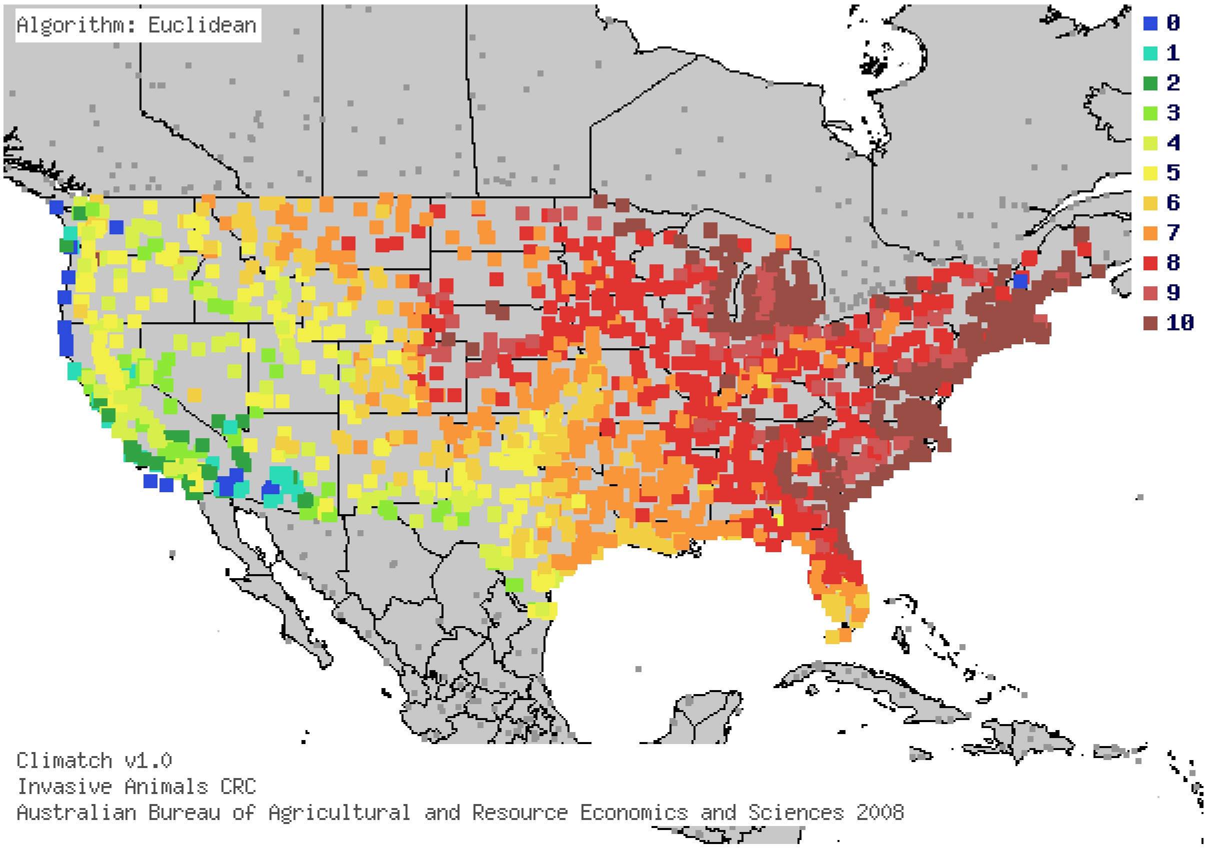

Figure 4. Map of CLIMATCH (Australian Bureau of Rural Sciences 2008) climate matches for *Alosa pseudoharengus* in the contiguous United States based on source locations reported by GBIF (2014) and Fuller et al. (2014). 0= Lowest match, 10=Highest match.

Table 1. CLIMATCH (Australian Bureau of Rural Sciences 2008) climate match scores.

CLIMATCH Score	0	1	2	3	4	5	6	7	8	9	10
Count	24	38	48	79	134	191	203	323	434	144	356
Climate 6 Proportion =		0.740									

7 Certainty of Assessment

Information on the biology, distribution, and impacts of this species is readily available. Certainty of assessment for this species is high.

8 Risk Assessment

Summary of Risk to the Contiguous United States

Alosa pseudoharengus is a marine and freshwater fish native to the Atlantic coast of North America and associated streams and rivers. This species has spread to the Great Lakes and various states through man-made channels and stocking. Climate match with the contiguous U.S. is high. *Alosa pseudoharengus* is an efficient zooplanktivore, and causes changes in the zooplankton community. Those changes can cause declines in native fishes, especially planktivorous salmonids. This species also consumes pelagic larvae of native fishes. Salmonids that consume *Alosa pseudoharengus* are at risk of a thiamine deficiency in their offspring. This species is prone to mass die-offs which are a nuisance for lakeshore property owners and the recreation industry. Overall risk for this species is high.

Assessment Elements

- **History of Invasiveness (Sec. 3):** High
- **Climate Match (Sec.6):** High
- **Certainty of Assessment (Sec. 7):** High
- **Overall Risk Assessment Category: High**

9 References

Note: The following references were accessed for this ERSS. References cited within quoted text but not accessed are included below in Section 10.

Australian Bureau of Rural Sciences. 2008. CLIMATCH. Available: http://data.daff.gov.au:8080/Climatch/climatch.jsp. (August 2014).

Froese, R., and D. Pauly. Editors. 2011. FishBase. Available: http://www.fishbase.de/summary/Alosa-pseudoharengus.html. (February 2011).

Fuller, P., E. Maynard, D. Raikow, J. Larson, A. Fusaro, and M. Neilson. 2014. *Alosa pseudoharengus*. USGS Nonindigenous Aquatic Species Database, Gainesville, Florida. Available: http://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=490. (August 2014).

Global Biodiversity Information Facility (GBIF). 2014. Available: http://www.gbif.org/species/2412740. (August 2014).

Global Invasive Species Database (GISD) 2011. *Alosa pseudoharengus*. Available from: http://www.issg.org/database/species/ecology.asp?si=625&fr=1&sts=&lang=EN. (February 2011).

ITIS. 2011. *Alosa pseudoharengus*. Integrated Taxonomic Information System. Available: http://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=161706. (February 2011).

O'Gorman, R. 2014. *Alosa pseudoharengus* (Alewife). CAB International, Wallingford, United Kingdom. Available: http://www.cabi.org/isc/datasheet/94217. (August 2014).

Whitehead, P.J.P. 1985. FAO Species Catalogue. Vol. 7. Clupeoid fishes of the world (suborder Clupeioidei). An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf-herrings. FAO Fisheries Synopsis 125(7/1): 1-303.

10 References Quoted But Not Accessed

Note: The following references are cited within quoted text within this ERSS, but were not accessed for its preparation. They are included here to provide the reader with more information.

Altman, P.L., and D.S. Dittmer. 1962. Growth, including reproduction and morphological development. Federation of American Societies for Experimental Biology.

Bean, T.H. 1882. Movements of young alewives (*Pomolobus* sp.) in Colorado River, Texas. Pages 69-70 *in* S. F. Baird, editor. Report of the Commissioner of Fiishes and Fisheries for 1881. Volume I. U.S. Commision of Fish and Fisheries, Washington, District of Columbia.

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison, Wisconsin. Available: http://digital.library.wisc.edu/1711.dl/EcoNatRes.FishesWI.

Bigelow, H.B., M.G. Bradbury, J.R. Dymond, J.R. Greeley, S.F. Hildebrand, G.W. Mead, R.R. Miller, L.R. Rivas, W.L. Schroeder, R.D. Suttkus, and V.D. Vladykov. 1963. Fishes of the western North Atlantic. Part three. Yale University, New Haven, Connecticut.

Bouc, K. 1987. The fish book. Nebraskaland Magazine 65(1): 1-130.

Brooks, J.L., and S.I. Dodson. 1965. Predation, body size, and composition of plankton. Science 150: 28-35.

Brown, S.B., J.D. Fitzsimons, V.P. Palace, and L. Vandenbyllaardt. 1998. Thiamine and early mortality syndrome in lake trout. Pages 18-25 *in* G. McDonald, J.D. Fitzsimons, and D.C. Honeyfield, editors. Early life stage mortality syndrome in fishes of the Great Lakes and Baltic Sea. American Fisheries Society, Symposium 21, Dearborn, Michigan, USA, 28 August 1996. American Fisheries Society, Bethesda, Maryland.

Brown, S.B., D.C. Honeyfield, J.G. Hnath, M. Wolgamood, S.V. Marcquenski, J.D. Fitzsimons, and D.E. Tillitt. 2005. Thiamine status in adult salmonines in the Great Lakes. Journal of Aquatic Animal Health 17(1): 59-64.

Burr, B.M., and L.M. Page. 1986. Zoogeography of fishes of the lower Ohio-upper Mississippi basin. Pages 287-324 *in* C. H. Hocutt, and E. O. Wiley, editors. The Zoogeography of North American Freshwater Fishes. John Wiley and Sons, New York, New York.

Burr, B.M., and M.L. Warren, Jr. 1986. A distributional atlas of Kentucky fishes. Kentucky Nature Preserves Commission Scientific and Technical Series 4.

Christie, W.J. 1972. Lake Ontario: effects of exploitation, introductions, and eutrophication on the salmonid community. Journal of the Fisheries Research Board of Canada 29: 913-929.

Crowder, L.B. 1984. Character displacement and habitat shift in a native cisco in southeastern Lake Michigan: Evidence for competition? Copeia 1984(4): 878-883.

Crowder, L.B., and F.P. Binkowski. 1983. Foraging behaviors and the interactions of alewife, *Alosa pseudoharengus*, and bloater, *Coregonus hoyi*. Environmental Biology of Fishes 8: 105-113.

Cudmore-Vokey, B., and E.J. Crossman. 2000. Checklists of the fish fauna of the Laurentian Great Lakes and their connecting channels. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2500.

Czypinski, G.D., A.K. Bowen, M.T. Weimer, and A. Dextrase. 2002. Surveillance for ruffe in the Great Lakes, 2001. U.S. Fish and Wildlife Service, Ashland, Wisconsin.

Dahlberg, M.D., and D.C. Scott. 1971. The freshwater fishes of Georgia. Bulletin of the Georgia Academy of Science 29: 1-64.

DeBruyne, R.L., T.L. DeVault, A.E. Duerr, D.E. Capen, F.E. Pogmore, J.R. Jackson, and L.G. Rudstam. 2012. Spatial and temporal comparisons of double-crested cormorant diets following the establishment of alweife in Lake Champlain, USA. Journal of Great Lakes Research 38(Supplement 1): 123-130.

Denoncourt, R.F., T.B. Robbins, and R. Hesser. 1975. Recent introductions and reintroductions to the Pennsylvania fish fauna of the Susquehanna River drainage above Conowingo Dam. Proceedings of the Pennsylvania Academy of Science 49: 57-58.

Eddy, S., and J.C. Underhill. 1974. Northern fishes, with special reference to the Upper Mississippi Valley, 3rd edition. University of Minnesota Press, Minneapolis, Minnesota.

Emery, L. 1985. Review of fish introduced into the Great Lakes, 1819-1974. Great Lakes Fishery Commission Technical Report, volume 45.

Etnier, D.A., and W.C. Starnes. 1993. The fishes of Tennessee. University of Tennessee Press, Knoxville, Tennessee.

Frimodt, C. 1995. Multilingual illustrated guide to the world's commercial coldwater fish. Fishing News Books, Oxford, England.

Gnaedinger, R.H. 1964. Thiaminase activity in fish: an improved assay method. U.S. Fish and Wildlife Service, Fishing Industry Research 2: 55-59.

Greenwood, M.R. 1970. 1968 state-federal Lake Michigan alewife die-off control investigation. U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries, Exploratory Fishing and Gear Research Base, Ann Arbor, Michigan.

Hartel, K.E. 1992. Non-native fishes known from Massachusetts freshwaters. Occasional Reports of the Museum of Comparative Zoology, Harvard University, Fish Department, Cambridge, Massachusetts.

Hauser, M. 1998. Champlain Canal fish barrier study. Aquatic Nuisance Species Digest 2(3): 26-27.

Hendricks, M.L., J.R. Stauffer, Jr., C.H. Hocutt, and C.R. Gilbert. 1979. A preliminary checklist of the fishes of the Youghiogheny River. Chicago Academy of Sciences, Natural History Miscellanea 203: 1-15.

Hocutt, C.H., R.E. Jenkins, and J.R. Stauffer, Jr. 1986. Zoogeography of the fishes of the central Appalachians and central Atlantic Coastal Plain. Pages 161-212 *in* C.H. Hocutt, and E.O. Wiley, editors. The Zoogeography of North American Freshwater Fishes. John Wiley and Sons, New York, New York.

Jenkins, R.E., and N.M. Burkhead. 1994. Freshwater Fishes of Virginia. American Fisheries Society, Bethesda, Maryland.

Johannsson, O.E. 2003. A history of changes in zooplankton community structure and function in Lake Ontario: Responses to whole-lake remediation and exotic invasions. Pages 221-256 *in* M. Munawar, editor. The State of Lake Ontario: Past, Present, and Future. Ecovision World Monograph Series, Aquatic Ecosystem Health and Management Society, Burlington, Ontario, Canada.

Jones, P.W., F.D. Martin, and J.D. Hardy Jr. 1978. Development of fishes of the Mid-Atlantic Bight. An atlas of eggs, larval and juvenile stages. Vol. 1. Acipenseridae through Ictaluridae. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-78/12.

Kelly, J.M. 2001. Bait-bucket biology. Post Standard, Syracuse, New York. (June 28, 2001).

Kelso, W.E., and J.J. Ney. 1983. Nocturnal foraging by alewives in reservoir coves. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies, 36: 125-134.

Ketola, H.G., P.R. Bowser, G.A. Wooster, L.R. Wedgeand, and S.S. Hurst. 2000. Effects of thiamine on reproduction of Atlantic salmon and a new hypothesis for their extirpation in Lake Ontario. Transactions of the American Fisheries Society 129(2): 607-612.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. 1980 et seq. Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, Raleigh, North Carolina.

Madenjian, C.P., R. O'Gorman, D.B. Bunnell, R.L. Argyle, E.F. Roseman, D.M.Warner, J.D. Stockwell, and M.A. Stapanian. 2008. Adverse effects of alewives on Laurentian Great Lakes fish communities. North American Journal of Fisheries Management 28: 263-282.

Marcquenski, S.V. 1996. Characterization of early mortality syndrome (EMS) in salmonids from the Great Lakes. Pages 73-75 *in* B.E. Bengtsson, C. Hill, and S. Nellbring, editors. Report from the second workshop on reproduction disturbances in fish, November 20-23, 1995. Swedish Environmental Protection Agency, Stockholm, Sweden.

Marsden, J.E., and M. Hauser. 2009. Exotic species in Lake Champlain. Journal of Great Lakes Research 35: 250-265.

McDonald, G., J.D. Fitzsimons, and D.C Honeyfield. 1998. Early life stage mortality syndrome in fishes of the Great Lakes and Baltic Sea. American Fisheries Society, Bethesda, Maryland.

Miller, R.R. 1957. Origin and dispersal of the alewife, *Alosa pseudoharengus*, and the gizzard shad, *Dorosoma cepedianum*, in the Great Lakes. Transactions of the American Fisheries Society 86: 97-111.

Minckley, W.L. 1973. Fishes of Arizona. Arizona Fish and Game Department. Sims Printing Company, Inc., Phoenix, Arizona.

Morris, J., L. Morris, and L. Witt. 1974. The Fishes of Nebraska. Nebraska Game and Parks Commission, Lincoln, Nebraska.

O'Gorman, R., and T.J. Stewart. 1999. Ascent, dominance, and decline of the alewife in the Great Lakes: food web interactions and management strategies. Pages 489-514 *in* W. W. Taylor, and P. Ferreri, editors. Great Lakes Policy and Management: A Binational Perspective. Michigan State University Press, East Lansing, Michigan.

O'Gorman R., C.P. Madenjian, E.F. Roseman, A.Cook, and O.T. Gorman. In press. Alewife in the Great Lakes: Old invader - New millennium. *In* W.W. Taylor, A.M. Lynch, and N.J. Leonard, editors. Great Lakes Fisheries Policy and Management: A Binational Perspective. Michigan State University Press, East Lansing, Michigan.

Page, L.M., and C.A. Laird. 1993. The identification of the nonnative fishes inhabiting Illinois waters. Report prepared by Center for Biodiversity, Illinois Natural History Survey, Champaign, for Illinois Department of Conservation, Springfield. Center for Biodiversity Technical Report 1993(4).

Phillips, G.L., W.D. Schmid, and J.C. Underhill. 1982. Fishes of the Minnesota Region. University of Minnesota Press, Minneapolis, Minnesota.

Pritchard, A.L. 1929. The alewife (*Pomolobus pseudoharengus*) in Lake Ontario. Publication of the Ontario Fisheries Research Laboratory 38: 37-54. [University of Toronto Studies Biological Series Publication 33.]

Riede, K. 2004. Global register of migratory species - from global to regional scales. Final Report of the R&D-Projekt 808 05 081. Federal Agency for Nature Conservation, Bonn, Germany.

Robins, C.R., and G.C. Ray. 1986. A field guide to Atlantic coast fishes of North America. Houghton Mifflin Company, Boston, Massachusetts.

Rohde, F.C, R.G. Arndt, J.W. Foltz, and J.M. Quattro. 2009. Freshwater Fishes of South Carolina. University of South Carolina Press, Columbia, South Carolina.

Scott, W.B., and M.G. Scott. 1988. Atlantic fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences 219.

Simonin, P.W., D.L. Parrish, L.G. Rudstam, P.J. Sullivan, and B. Pientka. 2012. Native rainbow smelt and nonnative alewife distribution related to temperature and light gradients in Lake Champlain. Journal of Great Lakes Research 38(Supplement 1): 115-122.

Smith, S.H. 1970. Species interactions of the alewife in the Great Lakes. Transactions of the American Fisheries Society 99(4): 754-765.

Smith, P.W. 1979. The Fishes of Illinois. University of Illinois Press, Urbana, Illinois.

Smith, C.L. 1985. The Inland Fishes of New York State. New York State Department of Environmental Conservation, Albany, New York.

Stauffer, J.R., Jr., J.M. Boltz, and L.R. White. 1995. The Fishes of West Virginia. Academy of Natural Sciences of Philadelphia, Philadelphia, Pennsylvania.

Tilmant, J.T. 1999. Management of nonindigenous aquatic fish in the U.S. National Park System. National Park Service.

Todd, T.N. 1986. Artificial propagation of coregonines in the management of the Laurentian Great Lakes. Archiv für Hydrobiologie–Beiheft Ergebnisse der Limnologie 22: 31-50.

U.S. Environmental Protection Agency (USEPA). 2008. Predicting future introductions of nonindigenous species to the Great Lakes. EPA/600/R-08/066F. National Center for Environmental Assessment, Washington, District of Columbia. Available: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=190305.

Vermont Department of Environmental Conservation (VTDEC). 2002. Alewife Fact Sheet. Available: http://www.anr.state.vt.us/dec/waterq/ans/alewife.htm. (September 2003).

Warshaw, S.J. 1972. Effects of alewives (*Alosa pseudoharengus*) on the zooplankton of Lake Wononskopomuc, Connecticut. Limnology and Oceanography 17: 816-825.

Wells, L. 1970. Effects of alewife predation on zooplankton populations in Lake Michigan. Limnology and Oceanography 15: 556-565.