Alewife (*Alosa pseudoharengus*)
Ecological Risk Screening Summary

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1 Native Range and Status in the United States

Native Range

From Froese and Pauly (2019a):

"North America: Atlantic coast from Red Bay, Labrador in Canada to South Carolina in USA; many landlocked populations exist. […] Native to Lake Ontario; […]"

Status in the United States

From Froese and Pauly (2019a):

"[…]; introduced into other Great Lakes via Welland Canal (first taken in Lake Erie in 1931). Introduced elsewhere, including New River in West Virginia and Virginia, and upper Tennessee River system in Tennessee, USA."

From Fuller et al. (2019a):

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

"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)."

From Fuller et al. (2019b):

"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)."

"*Alosa pseudoharengus* is a regulated invasive species in Minnesota (MN Administrative Rules, 6216.0260 Regulated). New York restricts the use of alewife as bait in most waters (6 NYCRR Part 19). While not listed by name, in Ohio it is illegal for any person to possess, import or sell exotic species of fish (including *Alosa pseudoharengus*) or hybrids thereof for introduction or to release into any body of water that is connected to or otherwise drains into a flowing stream or other body of water that would allow egress of the fish into public waters, or waters of the state, without first having obtained permission (OAC Chapter 1501:31-19)."

Additionally, Fuller et al. (2019a) list nonindigenous occurrences of *Alosa pseudoharengus* in Alabama since 2018, Maryland since 1979, and North Carolina since 1999.

From GISD (2017):

"Alewife is native along Atlantic coast of New York, it is however invasive in western New York outside of the Atlantic drainage (Robert O Gorman., pers. comm 2004)."

From CABI (2019):

"Established populations of *A. pseudoharengus* in North American waterbodies are mainly in the United States and in the easternmost part of the continent. All but a few are located east of the Mississippi River (USGS, 2009). The lone exceptions are in the north part of the state of Nebraska. Although there are records of alewife in the western state of Colorado (Minckley, 1973; USGS, 2009), the fish was not recently listed as being present in that state (Johnson and Nomanbhoy, 2005)."

"*A. pseudoharengus* had been present in Lake Ontario, the fifth and easternmost of the interconnected Great Lakes, since the mid-1800s and had been abundant there since the late 1870s (O'Gorman and Stewart, 1999). Although Lake Ontario drains to the Atlantic Ocean through the 500-km long St. Lawrence River, it is generally believed that *A. pseudoharengus* is not native to Lake Ontario, mainly because of its absence from the historical record until hundreds of years after the arrival of European colonists. Moreover, there is also genetic evidence that suggests alewife were not indigenous to Lake Ontario (Ihssen et al., 1992). There is no agreement on how *A. pseudoharengus* may have invaded Lake Ontario (Daniels, 2001); some have suggested migration through navigation canals or perhaps inadvertent introduction from planned releases of other fishes (Miller, 1957; Smith, 1970)."

Means of Introductions in the United States

From Fuller et al. (2019a):

"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)."

From CABI (2019):

"There is no agreement on how *A. pseudoharengus* may have invaded Lake Ontario (Daniels, 2001); some have suggested migration through navigation canals or perhaps inadvertent introduction from planned releases of other fishes (Miller, 1957; Smith, 1970)."

Remarks

A previous version of this ERSS was published in 2014.

Alosa pseudoharengus has landlocked and anadromous populations. The climate match and results of the screening only take into account freshwater populations and stages and the results are only applicable for freshwater locations.

From GISD (2017):

"Describing the distribution of alewife is difficult as native and invaded ranges overlap. For example, alewife is native along Atlantic coast of New York, however it is invasive in western New York outside of the Atlantic drainage (Robert O'Gorman, pers. comm. 2004)"

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

From Fricke et al. (2019):

"**Current status:** Valid as *Alosa pseudoharengus* (Wilson 1811)."

From ITIS (2019):

"Kingdom Animalia
Subkingdom Bilateria
Infrakingdom Deuterostomia
Phylum Chordata
Subphylum Vertebrata
Infraphylum Gnathostomata
Superclass Actinopterygii
Class Teleostei
Superorder Clupeomorpha
Order Clupeiformes
Suborder Clupeoidei

Family Clupeidae
Subfamily Alosinae
Genus *Alosa*
Species *Alosa pseudoharengus* (Wilson, 1811)"

Size, Weight, and Age Range

From Froese and Pauly (2019a):

"Maturity: L_m ?, 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 Froese and Pauly (2019a):

"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]."

From CABI (2019):

"In the Laurentian Great Lakes, the depths occupied by *A. pseudoharengus* change seasonally and vary somewhat among lakes due to differences in bathymetry and temperature regimes (Wells, 1968; O'Gorman and Schneider, 1986; O'Gorman et al., 2000). In general, *A. pseudoharengus* overwinter offshore in deep water and move shoreward into shallower water in spring to spawn, after which they move back to open waters where they remain throughout the summer, occupying mid to upper levels in the water column (Bergstedt and O'Gorman, 1989; O'Gorman et al., in press). In autumn, as the lakes cool, *A. pseudoharengus* descend to greater depths. The depth distribution of *A. pseudoharengus* within a lake can change, however, as it did in Lake Ontario following changes in the lake ecosystem (O'Gorman et al., 2000)."

"In summer, adult *A. pseudoharengus* in the Great Lakes avoid the cold hypolimnetic waters and occupy the warm epilimnetic waters although under certain conditions they [*sic*] some can be found in the thermocline (Wells, 1968; Olson et al., 1988; Johannsson and O'Gorman, 1991; but see Janssen and Brandt, 1980). Laboratory temperature preferences for adult *A. pseudoharengus* were 21ºC in spring, 16-19ºC in summer, and 16 -20ºC in autumn (Otto et al., 1976; Spotila et al., 1979). Ultimate upper lethal temperatures were 31-34ºC for adult alewives acclimated to 20-27ºC (Otto et al., 1976; McCauley and Binkowski, 1982).

A. pseudoharengus are severely stressed by temperatures lower than 3ºC (Colby, 1973). In the Great Lakes *A. pseudoharengus* are in water at 1 to 3ºC during most winters. In severe winters, as water temperature may be at or below 1ºC (Mortimer, 1971; Rodgers, 1987), mass mortalities of *A. pseudoharengus* sometimes occur (O'Gorman and Schneider, 1986; Bergstedt and O'Gorman, 1989; O'Gorman et al., in press). […] When held in ponds where water temperatures were < 2ºC for more than six weeks, *A. pseudoharengus* experienced sublethal immunosuppression, increasing their susceptibility to disease (Lepak and Kraft, 2008)."

Climate/Range
From Froese and Pauly (2019a):

"Temperate; 52°N - 33°N, 93°W - 52°W [Page and Burr 2011]"

Distribution Outside the United States
Native
From Froese and Pauly (2019a):

"North America: Atlantic coast from Red Bay, Labrador in Canada to South Carolina in USA; many landlocked populations exist. […] Native to Lake Ontario; […]"

Introduced
From Fuller et al. (2019b):

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

Means of Introduction Outside the United States
From CABI (2019):

"There is no agreement on how *A. pseudoharengus* may have invaded Lake Ontario (Daniels, 2001); some have suggested migration through navigation canals or perhaps inadvertent introduction from planned releases of other fishes (Miller, 1957; Smith, 1970)."

Short Description
From Froese and Pauly (2019a):

"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.

From GISD (2017):

"Maine's Department of Marine Resources (1998) states that *A. pseudoharengus* is an iridescent gray green or violet shade on top that fades down their sides to a silver underbelly. It usually has a distinct dusky spot just behind the upper margin of the gill cover. Its strongly laterally compressed body is three and one-third times as long as it is deep and has a forked tail fin. The midline of their belly is sharp and saw edged. Serrations located on the midline of their belly are much stronger and sharper than the ones found on most other members of their family."

From CABI (2019):

“Eyes are large. The front of the lower jaw is thick and extends past the upper jaw when the mouth is closed. The maxillary extends to below the middle of the eye. […] There are more than 30 gill rakers on the lower angle of the first gill arch (Trautman, 1957). The single dorsal fin usually has 13-14 rays but may have 12-16. […] The anal fin is short and wide with 15-19 rays (usually 17-18). The pelvic fins are rather small and contain 10 rays. The pectoral fins are low on the sides and they usually have 16 rays but may have as few as 14 (Scott and Crossman, 1973).”

Biology

From Froese and Pauly (2019a):

“Occurs in open water over all bottom types [Page and Burr 2011]. 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].”

“Spawning activity has been observed both diurnally and nocturnally, but with greatest activity at night [Edsall 1964]. Spawning activity stops above 27.8°C [Edsall 1970]. Freshwater populations mature earlier and at a smaller average size than saltwater populations [Jones et al. 1978].”

“Feed on planktonic and benthic invertebrates [Mills et al. 1995]. Fish measuring 5.0-7.0 cm TL feed by gulping, filtering and particulate feeding, whereas smaller fish are exclusive particulate feeders [Lazzaro 1987].”

From CABI (2019):

“In the Laurentian Great Lakes, *A. pseudoharengus* are found in schools during daylight hours. At night, the schools break up and some of the fish move to waters near shore. Larval *A. pseudoharengus* are pelagic and are found in bays as well as in nearshore waters around the periphery of Lake Huron and Lake Ontario (O’Gorman, 1983; Klumb et al., 2003). Young-of-year *A. pseudoharengus* in Lake Michigan prefer rocky substrate over sandy substrate when near shore (Janssen and Luebke, 2004). The young of anadromous *A. pseudoharengus* migrate to the Atlantic after spending their first summer in fresh water whereas the young of Great Lakes *A. pseudoharengus* move farther from shore as they grow, overwintering in deep water with their parents.”

“The minimum temperature at which Atlantic *A. pseudoharengus* spawn is 10ºC (Cianci, 1965) and spawning peaks at 13-16ºC (Richkus, 1974; Tyus, 1974). In landlocked populations, the spawning period is protracted, lasting more than a month (Odell, 1934; Norden, 1967; Hlavek and Norden, 1978). Mean fecundity of Lake Michigan *A. pseudoharengus* was 11,150 for fish averaging 160 mm total length, 16,140 for fish averaging 176 mm, and 22,400 for fish averaging 192 mm (Norden, 1967; Hlavek and Norden, 1978). The non-adhesive eggs are demersal and are broadcast at random over any type of bottom (Odell, 1934; Mansueti, 1956). Optimum temperature for egg incubation is 17.8ºC and incubation time varies from 15 days at 7.2ºC to 3.7 days at 21.1ºC (Edsall, 1970). Alewife larvae average 3.8 mm at hatching, 5.1 mm at yolk sac absorbtion, and, when held at 20ºC, they begin feeding two days after hatching (Norden, 1967; Heinrich, 1981). The larvae are positively phototropic and pelagic (Odell, 1934)."

"*A. pseudoharengus* in Lake Michigan begin spawning when water temperatures reach about 15.6ºC; spawning is interrupted when water temperatures exceed 27.8ºC (Edsall, 1970). Eggs hatch when incubated at 6.9 to 29.4ºC but not at lower or higher temperatures. About 69% of the larvae from eggs incubated at less than 10.6ºC are deformed and not likely to survive. Alewife young-of-year (YOY) have been found at 16 to 29ºC in Lake Michigan (Brandt, 1980; Dufour et al., 2008). Laboratory studies show a YOY temperature preference range of 21 to 31ºC (Otto et al., 1976; Spotila et al., 1979) and critical thermal maximum range of 32 to 34ºC for YOY acclimated to 20-25ºC (Otto et al., 1976). In the Laurentian Great Lakes, *A. pseudoharengus* must grow to a total length of 60 mm or longer if they are to survive the winter (O'Gorman and Stewart, 1999). *A. pseudoharengus* are rare in Lake Superior, the northern-most Great Lake, presumably because the short growing season does not allow most young *A. pseudoharengus* sufficient time to grow to a size that would allow successful overwintering (O'Gorman et al., 1997; O'Gorman et al., in press)."

"Land-locked *A. pseudoharengus* eat zooplankton throughout their life (Morsell and Norden, 1968; Mills et al., 1992, 1995; Stewart et al., 2009). They are size-selective feeders, preferentially eating the largest available zooplankters (Kohler, 1980). Indeed, the movements of *A. pseudoharengus* around a large lake or the magnitude of an alewife population can sometimes be tracked by the size and species composition of zooplankton (Wells, 1970; Warshaw, 1972; O'Gorman et al., 1991). The first food of larval alewife is cyclopoid copepodites and as the larvae grow they incorporate larger zooplankton in their diet (Heinrich, 1981). When the fish grow to about 110-119 mm they begin to feed on larger invertebrates (Morsell and Norden, 1968) - amphipods, insects, and, in the Laurentian Great Lakes, the opossum shrimp *Mysis diluviana* and the bloody-red shrimp *Hemimysis anomola* (Walsh et al., 2008; Stewart et al., 2009; Lantry et al., 2010). *A. pseudoharengus* are adept at capturing prey in mid-water but have difficulty capturing prey located on or near the lake bottom (Janssen, 1978a). They can feed in the dark (Janssen, 1978b; Janssen et al., 1995; Kelso and Ney, 1983) and they have three modes of feeding: particulate, filtering, and gulping (Janssen, 1976). Nocturnal movement of *A. pseudoharengus* to nearshore areas of lakes to feed has been recorded (Kelso and Ney, 1983). Conversely, *A. pseudoharengus* have been found feeding at night far offshore in the Great Lakes on vertically migrating *Mysis* (Boscarino et al., 2009). *A. pseudoharengus* also eat their own larvae (Odell, 1934; Rhodes et al., 1974) as well as the larvae of other fishes and small young-of-year fishes (Kohler and Ney, 1980; Brandt et al., 1987; Kreuger et al., 1995)."

Human Uses

From Froese and Pauly (2019a):

"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]."

From CABI (2019):

"Commercial harvest of the low-value alewife was not economically viable […]"

From NatureServe (2019):

"In last 2 decades has gained in recognition and interest as source of fish meal, fish oil, and fish protein, especially for the animal food industries (Fay et al. 1983). However, has declined in commercial importance in South Atlantic region in recent decades (Bozeman and Van Den Avyle 1989)."

Diseases

Infection with infectious salmon anaemia virus is an OIE-reportable disease (OIE 2019).

From Froese and Pauly (2019a):

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

Froese and Pauly (2019b) list *Alosa pseudoharengus* as a host for *Brachyphallus crenatus*, *Clavellisa cordata*, *Opecoeloides vitellosus*, *Hemiurus appendiculatus*, and *H. levinseni*.

Poelen et al. (2014) list *Alosa pseudoharengus* as a host for *Paenibacillus thiaminolyticus*.

The Panel on Animal Health and Welfare (2008) lists *A. pseudoharengus* as a potential host for infectious salmon anaemia virus.

Threat to Humans

From Fuller et al. (2019a):

"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)."

3 Impacts of Introductions

From Fuller et al. (2019a):

"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. […] Alewife has recently become the dominant prey item for double-crested cormorants in Lake Champlain (DeBruyne et al. 2012). […] Pothoven et al. (2013) documented an increased abundance of age-0 yellow perch (*Perca flavescens*) and changes in the zooplankton community structure in Saginaw Bay, Lake Huron following the disappearance of alewife, including increased abundance of cladocerans (e.g., *Daphnia* spp., *Bythotrephes*, *Leptodora*) and decreased abundance of cyclopoid copepods."

"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 Fuller et al. (2019b):

"As the abundance of alewife continued to increase in the absence of predators, massive annual die-offs of alewife began in Lake Ontario, Lake Huron, and Lake Michigan. Beaches and nearshore regions were littered with "huge windrows" of fish (Brown 1968), reportedly removed by bulldozer (Alewife explosion 1967)."

"It was estimated that alewife populations were responsible for 28% of the total consumption (by wet weight) in Lake Michigan in 1987, and 96% of the total predation on invertebrates in Lake Ontario in 1990 (Rand et al. 1995). The abundance of alewife combined with a diet preference of zooplankton and larval fishes has been shown to affect both the zooplankton community and certain native fish populations over time. Preference for macrozooplankton and microcrustaceans has shifted the zooplankton community structure towards a prevalence of small species. Following an alewife decline in Lake Michigan in the mid 1970s, Evans (1990) noted a significant increase in abundance of *Limnocalanus macrurus* and *Diaptomus sicilis*, two of the largest copepods. Similarly, a 1987-1995 study of Lake Ontario found that abundances of cyclopoids and other larger species of zooplankton increased during this period of alewife decline (Johannsson et al. 1998). Changes in zooplankton abundance and structure caused by alewife can lead to changes in the phytoplankton community (Shapiro et al. 1975).

Disappearance of native planktivorous salmonids, such as lake whitefish (*Coregonus clupeaformis*), in the Great Lakes has been attributed in part to the introduction of alewife because of reduced zooplankton populations (Crowder and Binkowski 1983, Page and Laird 1993, Todd 1986). […] Smith (1970) attributed the extermination of the cisco and decline of chub species in the Great Lakes to the alewife. Smith (1970) also discussed the various interrelated changes that took place in each of the Great Lakes as alewife abundance increased. Christie (1972), on the other hand, argued that the alewife was not responsible for these changes.

In a review of the adverse effects of alewife on Great Lake fish communities, Madenjian et al. (2008) presented evidence that agreed with Eck and Wells (1987), who stated that alewife likely has a larger effect on native fish populations through predation of larvae than competition for food resources. Using time-series data for various fish populations along with change point regression analysis, they concluded that predation of larvae by alewife likely contributed to the decline of yellow perch (*Perca flavescens*), deepwater sculpin (*Myoxocephalus thompsonii*), burbot (*Lota lota*), Atlantic salmon (*Salmo salar*), lake trout (*Salvelinus namaycush*), and emerald shiner (*Notropis atherinoides*) (Madenjian et al. 2008).

Furthermore, alewife has an elevated level of thiaminase, an enzyme that can degrade thiamine in those species that prey on alewife (Tillitt et al. 2005). Alewife has thus been shown to cause thiamine deficiency and, consequently, early mortality syndrome (EMS) in populations of alewife predators. EMS and its adverse effects on recruitment and fish populations is well-documented for coho salmon (*Oncorhynchus kisutch*), lake trout, and Atlantic salmon (in which it is also referred to as Cayuga syndrome), among other fishes (Fitzsimons et al. 1999, Ketola et al. 2000, Madenjian et al. 2008). In a spawning reef in Lake Ontario, 50–75% of newly hatched lake trout fry were estimated to suffer from EMS from 1992-1999 (Mills et al. 2005)."

"*Alosa pseudoharengus* is a regulated invasive species in Minnesota (MN Administrative Rules, 6216.0260 Regulated). New York restricts the use of alewife as bait in most waters (6 NYCRR Part 19). While not listed by name, in Ohio it is illegal for any person to possess, import or sell exotic species of fish (including *Alosa pseudoharengus*) or hybrids thereof for introduction or to release into any body of water that is connected to or otherwise drains into a flowing stream or other body of water that would allow egress of the fish into public waters, or waters of the state, without first having obtained permission (OAC Chapter 1501:31-19)."

From CABI (2019):

"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.

The largest positive economic impact was the development of multi-million dollar recreational fisheries for hatchery-raised salmon and trout in the Laurentian Great Lakes (Bence and Smith, 1999; Connelly and Brown, 2009) -- *A. pseudoharengus* provides an important food source for these fish. These new fisheries are hatchery-dependent, however, and thus require large capital investments to start and continuing investments of capital to maintain."

From Simonin et al. (2018):

"The observed change in Walleye $\delta^{15}N$ values since 1997 is consistent with a change in Walleye diets to more Alewives in 2011. In 1997, nearly all Walleyes sampled in the main lake had consumed only Rainbow Smelt, mostly of lengths 50–175 mm […]. Our calculations of Walleye trophic levels (based $\delta^{15}N$ and a 3.4 unit fractionation per trophic level; Post 2002) resulted in a decline of about one trophic level for Walleyes from 1997 to 2011. This decline is likely caused by consumption of Alewives in 2011, a prey fish feeding at lower trophic levels than adult Rainbow Smelt […]. Yellow Perch *Perca flavescens* are consumed by Walleyes in other lakes (e.g., Lantry et al. 2008), but our previous research in Lake Champlain found that Yellow Perch were consumed by Walleyes only in the southern region of the lake (Overman and Parrish 2001). This section of the lake does not support Rainbow Smelt so was not included in this study. The change in Walleye diets to prey that feed at lower trophic levels (such as Alewives) will decrease the biomagnification of contaminants and increase the efficiency of energy flow through the ecosystem to Walleyes."

"Alewives have altered the trophic structure of the fish community in Lake Champlain and are likely to remain as influential as they have been in several of the Laurentian Great Lakes since the mid-20th century (e.g., Crowder 1980; Bunnell et al. 2006; Madenjian et al. 2008)."

4 Global Distribution

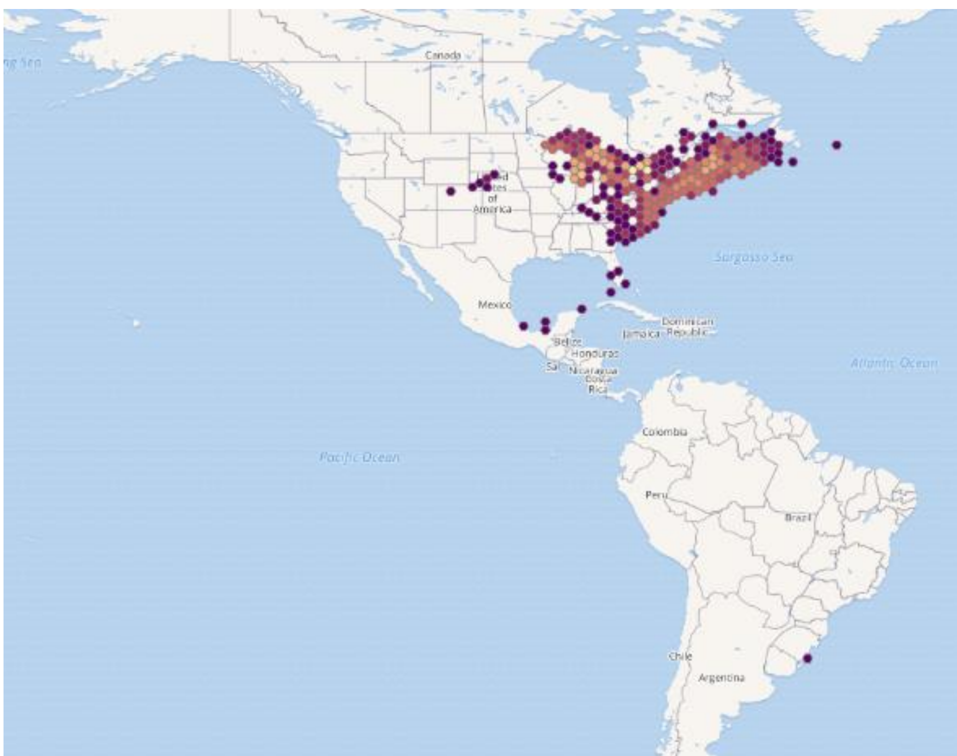

Figure 1. Known global distribution of *Alosa pseudoharengus*. Map from GBIF Secretariat (2019). The location in South America was not used to select source points for the climate match; the validity of the record is in question. The locations in Florida and Mexico were not

used to select source locations for the climate match; occurrence of the species there is not supported in the literature. The location in Colorado was not used to select source points for the climate match; establishment at this location is unknown.

Figure 2. Additional known global distribution of *Alosa pseudoharengus*. Map from Froese and Pauly (2019). The location in South America was not used to select source points for the climate match; the validity of the record is in question. The locations in Florida and Mexico were not used to select source locations for the climate match; occurrence of the species there is not supported in the literature.

Marine locations in Figures 1 and 2 were not used to select source points for the climate match. The climate match is only valid for freshwater and brackish water locations and source points can only be selected in those areas.

5 Distribution Within the United States

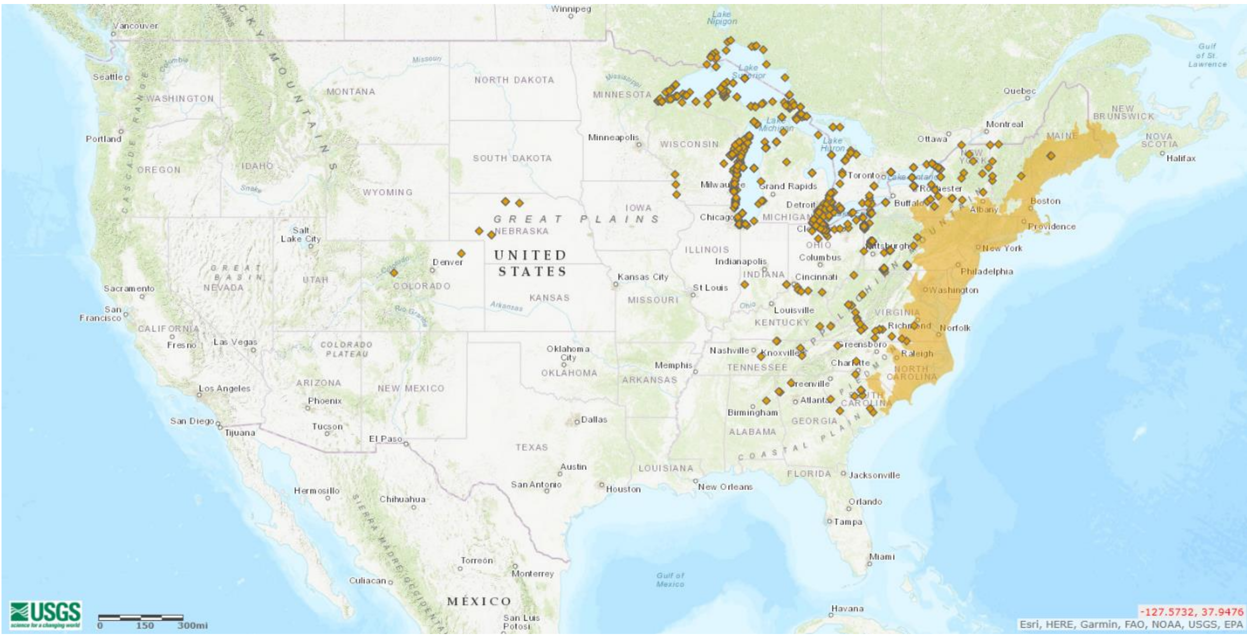

Figure 3. Known distribution of *Alosa pseudoharengus* in the United States. Yellow shading indicates the native range of the species. Map from Fuller et al. (2019a). The locations in Alabama and Colorado were not used to select source points for the climate match; establishment at these locations is unknown.

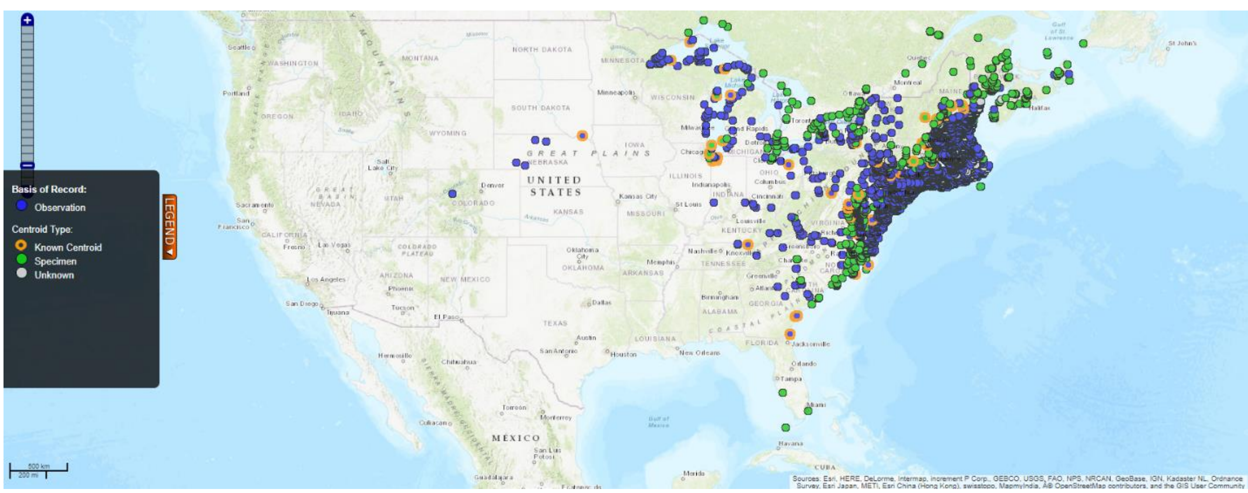

Figure 4. Additional known distribution of *Alosa pseudoharengus* in the contiguous United States. Map from BISON (2019). The location in Colorado was not used to select source points for the climate match; establishment at this location is unknown. The locations in Florida and Mexico were not used to select source points for the climate match; species presence in those areas was not supported by the literature.

6 Climate Matching

Summary of Climate Matching Analysis

The climate match for *Alosa pseudoharengus* to the contiguous United States was generally high in the eastern two thirds and low along the Pacific Coast. The climate match was high along the Atlantic Coast from Maine to mid-Florida, along the Gulf Coast from mid-Florida to eastern Texas, and west to the northern and central Great Plains. Southern Florida had a medium climate match. There was a small patch of low match in the southern Appalachian Mountains. The climate match was also low in central Texas, along the Mexican border, and the entire Pacific Coast, inland to just east of the Rocky Mountains. The Climate 6 score (Sanders et al. 2018; 16 climate variables; Euclidean distance) for contiguous United States was 0.668, high (scores of 0.103 and greater are considered high). All states had high individual climate scores except for Arizona, Idaho, and Nevada which had medium scores, and California, Oregon, and Washington which had low scores. The climate match is valid for freshwater and brackish water areas only.

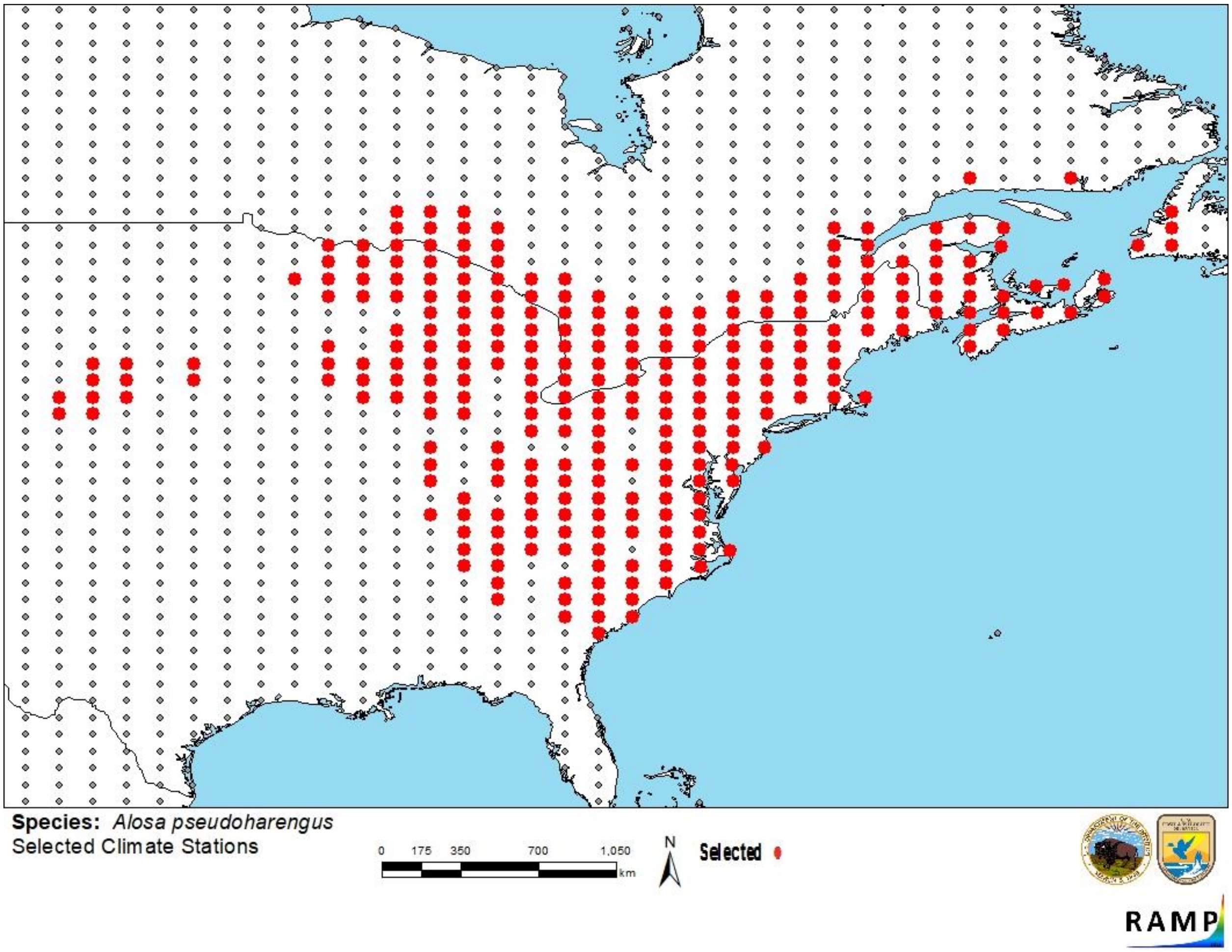

Figure 5. RAMP (Sanders et al. 2018) source map showing weather stations in North America selected as source locations (red; United States and Canada) and non-source locations (gray) for *Alosa pseudoharengus* climate matching. Source locations from BISON (2019), Fuller et al. (2019a), Froese and Pauly (2019), and GBIF Secretariat (2019).

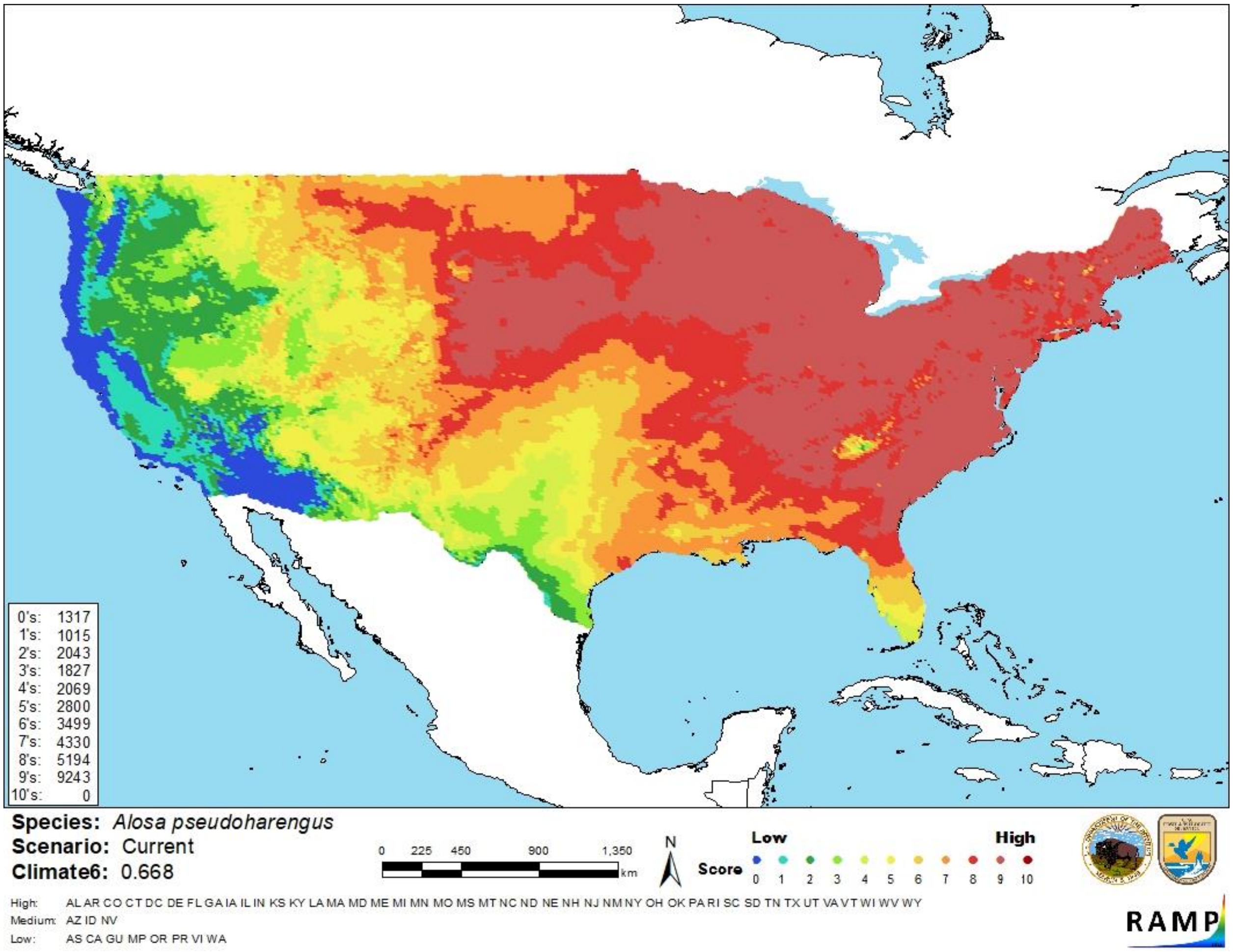

Figure 6. Map of RAMP (Sanders et al. 2018) climate matches for *Alosa pseudoharengus* in the contiguous United States based on source locations reported by BISON (2019), Fuller et al. (2019a), Froese and Pauly (2019), and GBIF Secretariat (2019). 0 = Lowest match, 10 = Highest match.

The High, Medium, and Low Climate match Categories are based on the following table:

Climate 6: Proportion of (Sum of Climate Scores 6-10) / (Sum of total Climate Scores)	Climate Match Category
$0.000 \leq X \leq 0.005$	Low
$0.005 < X < 0.103$	Medium
≥ 0.103	High

7 Certainty of Assessment

Certainty of assessment for this *Alosa pseudoharengus* is high. Information on the biology, distribution, and impacts of this species are well-documented from peer-reviewed sources. The literature does have some disagreement about impacts of introduction. The climate match does not cover the marine portion of the range.

8 Risk Assessment

Summary of Risk to the Contiguous United States

Alewife (*Alosa pseudoharengus*) is an anadromous marine and freshwater fish native to the Atlantic coast of North America and associated streams and rivers. The species generally consumes plankton and is a prey species in both the native and introduced ranges. There is some human consumption of the species and it is used as bait and for fish meal. Commercial harvesting is not economically sustainable. The history of invasiveness is high. This species spread to the Great Lakes and various states through man-made channels, such as the Erie and Welland canals, and stocking, and is now established. *A. pseudoharengus* is an efficient zooplanktivore, and causes changes in the zooplankton community. Those changes and direct competition caused declines in native fishes, especially planktivorous coregonids; although there is some disagreement in the literature about this. Salmonids that consume *A. pseudoharengus* are at risk of a thiamine deficiency, resulting in Early Mortality Syndrome, in their offspring which has severely impacted populations. *A. pseudoharengus* is prone to mass die-offs, which are a nuisance for lakeshore property owners and have a negative economic impact on the recreation industry. There may be some beneficial impacts through a reduction in biomagnification of contaminants in Walleye as *A. pseudoharengus* are on a lower trophic level than the Walleye's native prey. State level regulations affecting *A. pseudoharengus* are in place in Minnesota, New York, and Ohio. The overall climate match for the contiguous United States is high. Almost the entire eastern two-thirds of the contiguous United States (including the native range of the species) had a high climate match. Low climate matches were found along the Pacific Coast and the Mexican border. The climate match is valid for freshwater and brackish water areas only. The certainty of assessment is high. The biology of the species, distribution, and history of invasiveness is well documented. 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**
- **Remarks/Important additional information:** Possibly susceptible to an OIE-reportable disease (salmon anaemia virus).
- **Overall Risk Assessment Category: High**

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