American Eel (*Anguilla rostrata*)

Ecological Risk Screening Summary

U.S. Fish & Wildlife Service, December 2020
Revised, December 2020
Web Version, 8/31/2021

Organism Type: Fish
Overall Risk Assessment Category: Uncertain

Photo: Clinton and Charles Robertson. Licensed under Creative Commons Attribution 2.0 Generic. Available: https://commons.wikimedia.org/wiki/File:American_eel_(Anguilla_rostrata)_(4015394951).jpg (September 2020).

1 Native Range and Status in the United States

Native Range

From Froese and Pauly (2020):

"Northwest to western Central Atlantic: Greenland south along the Atlantic coast of Canada and the USA to Panama, and throughout much of the West Indies south to Trinidad."

From Fuller et al. (2019a):

"*Anguilla rostrata* is a catadromous species that spawns in the Sargasso Sea of the Western Atlantic and ascends streams in North and South America to live its adult stage in freshwater (Lee 1980, Simon 1999, Smith 1997). Its range extends from Greenland south down the Atlantic coast of Canada (including Newfoundland) and the USA, and as far south as Panama and Brazil. It is common throughout the Caribbean and West Indies. The Mississippi River and the Lake Ontario basin comprise its native freshwater range in the United States (Page and Burr 1991, Scott and Crossman 1973). Niagara Falls forms the edge of its native distribution within the Great Lakes (COSEWIC 2006)."

Status in the United States

From Fuller et al. (2019a):

"The Mississippi River and the Lake Ontario basin comprise its native freshwater range in the United States (Page and Burr 1991, Scott and Crossman 1973). Niagara Falls forms the edge of its native distribution within the Great Lakes (COSEWIC 2006)."

"**Status:** Failed in Arizona, California, Colorado, Nevada, and Utah. Established in Lake Erie drainages of Pennsylvania and Ohio.

Great Lakes (outside of native range)
Anguilla rostrata is present but uncommon in the upper Great Lakes (Becker 1983). Populations of *A. rostrata* are currently established in Lake Erie (Busch et al. 1977) and have been collected on multiple occasions from Lakes Michigan, Huron, and Superior where their establishment is uncertain."

According to Fuller et al. (2019a), *Anguilla rostrata* has been reported as nonnative in the following States (years of reports and watersheds given after State name):

- Arizona (1973-1994; Lake Mead; Lower Colorado Region)
- California (1874-2009; Lower Sacramento; Sacramento Headwaters; San Francisco Bay; San Francisco Coastal South; San Joaquin Delta; San Pablo Bay; Suisun Bay)
- Colorado (1986; San Luis)
- Illinois (1873; Little Calumet-Galien)
- Michigan (1957-1981; Betsy-Chocolay; Muskegon)
- Minnesota (1978; Beartrap-Nemadji)
- Nebraska (1873; Lower Elkhorn)
- Nevada (1973; Lake Mead)
- North Carolina (2000; Nolichucky)
- Ohio (1844-1986; Cedar-Portage; Cuyahoga; Lake Erie; Sandusky)
- Pennsylvania (1977-1997; French; Lake Erie)
- Utah (1872-1894; Jordan; Utah Lake)
- Wisconsin (1873-1977; Beartrap-Nemadji; Lake Michigan; Lake Superior; Lower Fox; St. Louis)

From Fuller et al. (2019b):

"In 1973, this species was stocked but failed to establish in Lake Mead on the Colorado River, near the Arizona border and in Nevada (Minckley 1973). More than one specimen has been since collected from an unspecified location in Arizona in 1994 (Rinne 1994). It was also stocked on several occasions in Sacramento and San Francisco bays, California, in the late 1800s, apparently with no evidence of survival (McCosker 1989, Shebley 1917, Smith 1896). Thirteen specimens were collected in the San Francisco area during the period from 1978 to 1984 (McCosker 1989, Williamson and Tabeta 1991). Specimens have been reported from the San Luis Valley, Conejos County, Colorado, where they escaped from an aquaculture facility (Zuckerman and Behnke 1986). Eels were stocked in the Calumet River south of Chicago, Illinois, in 1873 (Goode 1884, Milner 1874[…]). *Anguilla rostrata* was also reported as established in several localities in Indiana in 1945 (Gerking 1945). An 1873 stocking introduced the American eel to a river near Eaton, Michigan (Goode 1884, Milner 1874). This species was accidentally introduced into the Elkhorn River near Omaha, Nebraska, that same year, when a railroad car transporting East Coast fish to the West Coast lost its cargo to the river after a railroad bridge collapsed. An estimated 1,500 eels from Martha's Vineyard and 40,000 from the Hudson River were released into the Elkhorn (Smith 1896). In 2000, one American eel was collected in the Nolichucky River, North Carolina, but a population is not established (Shute and Etnier 2000). In the late 1800s, Ohio received transplants of hundreds of thousands of eels, which likely arrived through the Welland Canal (Trautman 1981). The American eel was stocked in Utah Lake and Salt Lake, Utah in the late 1800s, but it disappeared shortly thereafter (Popov and Low 1953, Sigler and Miller 1963). In 1873, *A. rostrata* was also stocked in the Fox River at Appleton, Wisconsin (Goode 1884, Milner 1874).

Great Lakes Occurrences (outside of native range)
First collected in Lake Superior from Alger County, Michigan at the mouth of Beaver Lake Creek, Pictured Rocks National Lakeshore in 1957. In 1970, a specimen was collected from the mouth of the Brule River in Douglas County, Wisconsin, and again in 1974 from Superior Harbor in Douglas County (Becker 1983). In 1978, an American eel was collected from the Blackhoof River in Carlton County, Minnesota, a tributary of the Nemadji River in the Lake Superior drainage (Cochran 1981). Although individuals have been observed in Lake Superior, the American eel is currently not believed to be established there (Mandrak 2009). Identified in 1935 in Port Washington, Ozaukee County, Wisconsin; collected from Green Bay at Red Banks in 1968 and again in 1974 from Green Bay at Pestigo Point in the Lake Michigan Basin. In 1977, this species was collected in Harrington Beach State Park, Ozaukee County, Wisconsin (Becker 1983). Eels have also been collected in Illinois and Indiana waters of Lake Michigan (Lee et al. 1980 et seq.) Earliest non-indigenous Great Lakes occurrence, collected in 1844 after traveling through the Welland Canal from Lake Ontario but did not become established (Trautman 1981). Collected from Maumee Bay, Lucas County, Ohio, in 1902 but again failed to establish (Trautman 1981). In 1977, the first established population was reported in Lake Erie, in Erie County, Pennsylvania after traveling through the Welland Canal (Busch et al. 1977)."

According to FAO (2020), *A. rostrata* has been introduced by the government to Guam from the United States, however, it has not become established there.

From California Department of Fish and Wildlife (2019):

"It shall be unlawful to import, transport, or possess live animals restricted in subsection (c) below except under permit issued by the department. […] Family Anguillidae-Freshwater Eels: All species of genus *Anguilla*"

Means of Introductions in the United States

From Fuller et al. (2019a):

"Intentionally stocked in most locations; accidentally stocked in the Elkhorn River, Nebraska; escaped from an aquaculture facility in Colorado. Since 1874, there have been many shipments of *A. rostrata* from the eastern United States to California to stock rivers and for fish farming purposes (Williamson and Tabeta 1991). Eels caught in California waters during the 1970s and 1980s are believed to have been imported by Japanese or Chinese restaurants or by fish farms, and the eels either escaped or were released (McCosker 1989, Williamson and Tabeta 1991). In Texas and South Carolina, eels were intentionally introduced for aquaculture and subsequently escaped from the aquaculture facility.

The American eel is thought to have gained access to the upper Great Lakes through the Welland Canal, connecting lakes Ontario and Erie (COSEWIC 2006, Scott and Crossman 1973). The canal opened in 1829, and the first record of the *Anguilla rostrata* above Lake Ontario was from Lake Erie in 1844 (Trautman 1981). While on Lake Ontario, early captains of Great Lakes vessels commonly carried a tub of eels for food. These eels were frequently thrown overboard when the crew either tired of them or procured better fishes as the vessels sailed through the Great Lakes (Goode 1884). Several thousand eels were later stocked into rivers in Illinois draining into Lake Michigan and into a river near Eaton, Michigan, gaining access to the Great Lakes on multiple fronts (Goode 1884). From 1877-1891, over 2.2 million eels were stocked in Michigan (Fukano et al. 1964)."

According to FAO (2020), *A. rostrata* was introduced to Guam for aquaculture and fisheries purposes.

Remarks

Anguilla rostrata can survive in fresh, brackish, and marine waters. The conclusions of this ERSS are valid for only fresh and brackish water areas.

From Fuller et al. (2019):

"Synonyms and Other Names: Anguille, black eel, bronze eel, glass eel, green eel, river eel, silver eel, yellow eel"

From Jacoby et al. (2017):

"IUCN Red List Category and Criteria [:] Endangered A2bd"

“Available data for this species indicates that, overall, there have been declines in recruitment, population and escapement over the period of three generations (36 years). However, the majority of data are for young yellow eels and the data available for older yellow eel populations and, most importantly, escaping silver eels, are limited and do not encompass the entire range of the species. These issues have been taken into account during the assessment process, and it would seem that applying criteria A2bd, as the limited available data indicates, the American Eel has seen a ~50% decline in silver eel escapement over three generations and thus is on the cusp of the Vulnerable and Endangered categories. Data relating to yellow eel recruitment and yellow eel populations would indicate that these metrics have declined to a slightly greater degree (50-60%) over three generations.

There are a suite of threats that have been implicated in causing the decline of American Eel recruitment and stocks; barriers to migration – including damage by hydropower turbines; poor body condition; climate change and/or changes in oceanic currents; disease and parasites (particularly *Anguillicola crassus*); exploitation and trade of glass, yellow and silver eels; hydrology; habitat loss; pollutants; and predation. The impacts of these threats individually or synergistically, are likely regionally specific, however, more broadly, climate and ocean currents have been suggested to play an important role in the survival of the leptocephalus larvae and recruitment of glass eels to coastal, brackish and freshwater habitat. Further research is required to fully understand the complexities of this particular aspect of the eel's life history but there are conflicting opinions as to the degree, if any, to which oceanic factors contribute to declines in eel numbers.

To date, the American Eel is not protected under any global treaties or conventions (e.g., CITES). However, in Canada, COSEWIC reviewed the status of the American Eel and revised the Canadian status from “Special Concern” in 2006, to “Threatened” in 2012. The Canadian government has commenced a response by initiating a Recovery Potential Assessment Review. In 2007, eels in Ontario were classified as “Endangered” under the Ontario Endangered Species Act and a Recovery Strategy was developed with an emphasis on restoring, protecting, and diversifying suitable habitat. The Ontario government is currently preparing a formal Response Statement addressing the recommendations in the Recovery Strategy. In the U.S, a review by the U.S Fish and Wildlife Service and the U.S. National Marine Fisheries Service is due to be completed in 2015 that will determine whether a listing of the species as Threatened, under the Endangered Species Act (ESA), is warranted.

Utilising the available historical data from range states, and taking into account the continued threats to this species, it was deemed appropriate to assign an IUCN listing of Endangered, using IUCN Red List Criteria, under past and current observations of population decline (A2bd). However, it is imperative to highlight that recruitment is increasing in some sites and that should management actions relating to anthropogenic threats prove effective, and/or there are positive effects of natural influences on the various life stages of this species, a listing of Vulnerable would be achievable. Further, a drive to fill data gaps – particularly in the southern range of this species - would increase the robustness of the assessment of this species. Another point to make is that it was not felt that the species was in immediate risk of extinction due to the wide geographic ranges they inhabit. However, this is not to say there wasn’t concern as to the species

status being ‘outside of safe biological limits’- for this assessment, ‘risk’ is determined based on past and present population levels.”

From USFWS (2019):

“Considering Endangered Species Act Protection
The U.S. Fish and Wildlife Service has reviewed the status of the American eel in 2007 and in 2015, finding both times that Endangered Species Act protection for the American eel is not warranted.
After examining the best scientific and commercial information available about the eel from Greenland south along the North American coast to Venezuela in South America and as far inland as the Great Lakes and the Mississippi River drainage, the Service found that the American eel is stable. While American eels still face local mortality from harvest and hydroelectric facilities, this is not threatening the overall species. Harvest quotas and mechanisms restoring eel passage around dams and other obstructions have also reduced these effects.”

Anguilla rostrata has been intentionally stocked outside its native range within the United States by State fishery managers to achieve fishery management objectives. State fish and wildlife management agencies are responsible for balancing multiple fish and wildlife management objectives. The potential for a species to become invasive is now one important consideration when balancing multiple management objectives and advancing sound, science-based management of fish and wildlife and their habitat in the public interest.

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

According to Fricke et al. (2020), *Anguilla rostrata* (Lesueur 1817) is the current valid name of this species. It was originally known as *Muraena rostrata* Lesueur 1817.

From ITIS (2020):

Kingdom Animalia
Subkingdom Bilateria
Infrakingdom Deuterostomia
Phylum Chordata
Subphylum Vertebrata
Infraphylum Gnathostomata
Superclass Actinopterygii
Class Teleostei
Superorder Elopomorpha
Order Anguilliformes
Suborder Anguilloidei
Family Anguillidae
Genus *Anguilla*
Species *Anguilla rostrata* (Lesueur, 1817)

Size, Weight, and Age Range

From Froese and Pauly (2020):

"Maturity: Lm ?, range 37 - 100 cm
Max length : 152 cm TL male/unsexed; [Smith 1997]; 122.0 cm TL (female); common length : 50.0 cm TL male/unsexed; [Wenner 1978]; max. published weight: 7.3 kg [IGFA 1991]; max. reported age: 43 years [Jessop 1987]"

Environment

From Froese and Pauly (2020):

"Marine; freshwater; brackish; demersal; catadromous [Smith 1997]; depth range 0 - 464 m [OBIS 2006]. […] 4°C - 25°C [Baensch and Riehl 1995; assumed to be recommended aquarium temperature]; […]"

Climate

From Froese and Pauly (2020):

"Subtropical; […] 66°N - 5°N, 98°W - 21°W"

Distribution Outside the United States

Native

Part of the native range for *Anguilla rostrata* is within the United States, see section 1 for a complete description of the native range.

From Fuller et al. (2019a):

"*Anguilla rostrata* is a catadromous species that spawns in the Sargasso Sea of the Western Atlantic and ascends streams in North and South America to live its adult stage in freshwater (Lee 1980, Simon 1999, Smith 1997). Its range extends from Greenland south down the Atlantic coast of Canada (including Newfoundland) and the USA, and as far south as Panama and Brazil. It is common throughout the Caribbean and West Indies.

Introduced

According to FAO (2020), *Anguilla rostrata* has been introduced to China from the United States, as well as Japan and Germany from Canada. The status of introduction in China and Japan is unknown. In Germany the status of introduction is listed as probably not established, however it is continuously stocked in that location.

From Fricke et al. (2020):

"Introduced in Italy."

From Marohn et al. (2014):

"Previous studies confirm that alien anguillid species have already been introduced into non-native waters […] American eels *Anguilla rostrata* (Lesueur 1817) in eastern Asian waters and considerable numbers of *A. rostrata* were reported from German rivers (Frankowski et al.,2009; Marohn et al., 2013 […]). Frankowski et al. (2009) detected that *A. rostrata* comprise 5–50% per anguillid haul in different German inland waters and Marohn et al.(2013 […]) identified 4.9% of migrating silver eels as *A. rostrata* during a 3 year monitoring programme in a German river system. […] Although *A. anguilla* and *A. rostrata* have overlapping spawning areas, any natural recruitment of *A. rostrata* to European waters is thought to happen rarely (Boëtius, 1980; Avise et al., 1990; Albert et al., 2006; Frankowski et al., 2009) […]"

From Fuller et al. (2019b):

"First collected in Lake Huron in 1957 from Goderich Harbor, Ontario in Canadian waters. A specimen was later collected in 1966 from Canadian waters in Macpherson Point near Underwood, ON. Again in 1973, this species was collected on three separate occasions in Canadian waters, including Nottawasaga Bay, the North Channel, and St. Mary's River near Macdonald, ON. In 1990 and 2000, two more collections from the Canadian waters of Lake Huron took place near the mouth of the Sauble River (Royal Ontario Museum 2011). There are no reports of this species being established in the American waters of Lake Huron."

According to Xiong et al. (2017), *Anguilla rostrata* is introduced and established in China in the Yellow Sea, East China Sea, South China Sea, however no further information on these populations could be found.

Means of Introduction Outside the United States

FAO (2020) lists the means of introduction of *Anguilla rostrata* as accidental and continuous stocking, outside the United States.

According to Xiong et al. (2017), *Anguilla rostrata* was introduced to China for its use in aquaculture.

From Marohn et al. (2014):

"Previous studies confirm that alien anguillid species have already been introduced into non-native waters […] American eels *Anguilla rostrata* (Lesueur 1817) in eastern Asian waters and considerable numbers of *A. rostrata* were reported from German rivers (Frankowski et al.,2009; Marohn et al., 2013 […]). Frankowski et al. (2009) detected that *A. rostrata* comprise 5–50% per anguillid haul in different German inland waters and Marohn et al.(2013[…]) identified 4.9% of migrating silver eels as *A. rostrata* during a 3 year monitoring programme in a German river system. […] the high numbers of *A. rostrata* recently observed in German waters are assumed to originate from the illegal stocking of imported fish (Frankowski et al., 2009). […] Crook (2010) estimated that c. 5000 t of living *A. rostrata* were imported into the European Union between 1998 and 2008. Despite being declared as aquaculture seed, it must be considered that imported

living *A. rostrata* may also be illegally used for stocking purposes to sustain inland and coastal eel fisheries, given the low availability and high demand for *A. anguilla* recruits (ICES, 2012)."

Short Description

From Froese and Pauly (2020):

"Dorsal spines (total): 0; Anal spines: 0. Head rather long; eyes small and placed well forward on head. Lips thick. Caudal vertebrae without transverse processes. Premaxillae not developed as distinct elements in adults. Frontal bones paired, not grown together. Pectoral girdle with 7 to 9 (up to 11 in the young) radial elements. Adults usually white or light-colored below and brownish to blue-black above, but coloration is variable; young with some yellow on the edges of the dorsal and anal fins [Greenfield and Thomerson 1997]. Caudal fin rounded, joined to dorsal and anal fins. Gill opening on side in front of lower half of well-developed pectoral fin; lower jaw longer than upper; 103-111 vertebrae [Smith 1997]."

From Fuller et al. (2019a):

"Elongated, snakelike body with a broad, depressed snout. Lower jaw extends beyond the upper jaw, and eyes are placed well forward on the head. The mouth is large and slightly oblique, with the gape extending to the posterior margin of the eye. One long dorsal fin originates far behind the pectorals and is continuous with the rounded caudal and anal fins. Pelvic fins are absent. One small gill slit is present in front of each pectoral fin. Scales are cycloid and embedded, and are difficult to see without magnification. The lateral line is well developed and prominent. Coloration varies depending on maturity level. The larval stage, known as the glass eel, is transparent and leaf shaped with a prominent black eye. This stage develops into an elver, which exhibits dark coloration from grayish green to brown. The first, sexually immature, adult stage has coloration ranging from yellow to olive-brown. Sexually mature adults have prominent black eyes and are dark brown to gray with a metallic sheen on their dorsal side and silver to white on their ventral side. During their spawning migration, coloration may transition from bronze to silver. As individuals mature, the eye develops a gold tinge known as "retinal gold" (Hardy 1978, Page and Burr 1991)."

Biology

From Froese and Pauly (2020):

"Occurs in streams, rivers, muddy or silt-bottomed lakes [Scott and Scott 1988]; usually in permanent streams with continuous flow [Page and Burr 2011]. Hides during the day in undercut banks and in deep pools near logs and boulders [Page and Burr 2011]. Feeds on larvae of Ephemeroptera, Odonata, Plecoptera, Coleoptera, Trichoptera, and Lepidoptera, as well as gastropods, oligochaetes, amphipods, isopods, mysids, and fish from the families Percidae, Cyprinidae, Ictaluridae, Catostomidae and Anguillidae [Lookabaugh and Angermeier 1992]. Migrates in autumn to the Sargasso Sea to spawn [Wenner 1978]. Sexual maturity occurs approximately in less than 10 years and up to 40 years in freshwater [Miller 1995]. Larvae (transparent leptocephali shaped somewhat like a willow leaf) hatch and develop at sea to metamorphose into elvers in nearshore waters and estuaries [Miller 2005]. Adults are caught

with eel pots and trot lines. Elvers and glass eels are caught with fine mesh fyke nets and dipnets. Catadromous species. [Smith 1997]."

"Undertakes migration in autumn to the Sargasso Sea where spawning is said to take place. Coloration changes with sexual maturation. Dorsal surface of the pectorals becomes dark, lateral line becomes prominent, eye diameter increases and visual pigments change, body takes on a silvery bronze coloration. Females are usually larger than males and migrate much farther upstream [Miller 2005]. Adults die after spawning [Greenfield and Thomerson 1997]. Spawn at sea but growth occurs in estuaries or freshwater [Bigelow and Schroeder 1953]. Spawning grounds believed to be between 20° and 30°N and 60°and 75°W [Schmidt 1925; Smith 1968]."

From Fuller et al. (2019a):

"*Anguilla rostrata* is catadromous, spawning in saltwater and returning to freshwater lakes, streams, and rivers to live its adult life. It is also considered a panmictic species, with all species members randomly mating as a single breeding population (COSEWIC 2006). Spawning occurs in autumn after migration to the Sargasso Sea, where eels hatch from eggs and are carried to the Atlantic coast after about one year of drifting through currents. These post-larval eels spend most of their time on the bottom in close proximity to shelter, such as burrows, plant masses, snags, and tubes (COSEWIC 2006, Fahay 1978, Van den Avyle 1984). By the time they reach shore, the eels have developed into their yellow adult form, although they are not yet sexually mature. In this phase, they are nocturnal carnivores, feeding on insects, fish, fish eggs, crabs, worms, clams, frogs, and dead animal matter (Lookabauch and Angermeier 1992). Eel density tends to decrease with distance from the sea in medium and large rivers, and it is thought that eel density drives the determination of sex structure in estuarine rivers: where eels are more concentrated, there are more likely to be males, and where eels are less concentrated, there are more likely to be females (COSEWIC 2006, USFWS 2006). As the American eel grows, it experiences a shift in diet, moving from primarily small insects to larger prey such as fish and crustaceans by the time it reaches a length of 400 mm (Ogden 1970).

Anguilla rostrata is a nocturnal species, taking shelter during the daylight hours (Baras et al. 1998, Van Den Avyle 1984). As an adult, *A. rostrata* prefers to live in streams with continuous flow or in muddy, silt bottomed lakes. Here, it spends most of its time at the bottom in search of food (Scott and Scott 1988). While small eels tend to be found in faster flowing water, larger eels are associated with slow, deep, and muddy habitats (Fahay 1978, Meffe and Sheldon 1988, Van Den Avyle 1984). The American eel possesses the ability to breathe through its skin, allowing it to travel over land and move around barriers in streams. It can tolerate a wide range of temperatures between 4 and 25°C but is sensitive to low dissolved oxygen levels (Baensch and Riehl 1995, Hill 1969, Sheldon 1974).

After as few as three years (or for females, as many as 40 years) living in freshwater, the American eel reaches sexual maturity and is ready to return to the Sargasso Sea to spawn (Miller 2005). Each individual becomes able to reproduce when it reaches a mature size, regardless of age. Individuals who spend their life in freshwater will grow slower than those who live in brackish water, meaning freshwater individuals will take much longer to become sexually mature. To prepare for their journey back to the sea, the American eel undergoes a wide variety

of physical changes. Its body pigmentation changes to have dark bronze to black dorsal sides with a silvery underside. Fat reserves increase, as well as the number of blood vessels feeding the swim bladder. Its eyes double in size and develop an increased sensitivity toward blue, giving the eel better vision in deep ocean water. Once back in the sea, females release between about 500,000 and 4,000,000 eggs, with large individuals (100 cm) capable of releasing up to 8,500,000 (Facey and Van den Avyle 1987). It is believed that the adult eels die after spawning occurs, as none have been observed migrating up rivers thereafter (Facey and Van den Avyle 1987)."

Human Uses

From Froese and Pauly (2020):

"Fisheries: commercial; aquaculture: commercial; gamefish: yes; aquarium: public aquariums"

From Jacoby et al. (2017):

"The various life stages, ranging from glass eel to adult, of all *Anguilla* species are harvested and traded on a global scale for consumption, with current demand predominantly driven by East Asian markets, in particular Japan and mainland China. A concerning pattern of exploitation is already apparent – when one Anguilla species or population becomes overexploited, industry moves to the next in order to fulfil demand (Crook and Nakamura 2013).

Anguilla spp. are traded internationally as live eels for farming and consumption, as fresh, frozen and smoked/prepared eels for consumption and as skins and leather products for fashion accessories. Global trade data collated by FAO for live, fresh, frozen and smoked/prepared Anguilla species (non-species specific) is available for the period 1976–2009. According to FAO data, global annual *Anguilla* exports averaged around 20,000 tonnes in the late 1970s (valued annually at 55–95 million US Dollars), after which annual exports showed a steady increase to a maximum of over 130,000 tonnes in 2000 (valued at over 1,000 million US Dollars). Since then annual exports have been declining, to just over 80,000 tonnes in 2008 and 2009 (valued at over 800 million US Dollars). By weight, China and Taiwan are responsible for nearly 75% of these exports and Japan for over 75% of all imports (FAO 2013).

Although American Eel has traditionally been consumed in small amounts domestically, in particular in the U.S. and Canada, harvesting is predominantly carried out with the purpose of export. Unlike in Europe or Asia, there is no tradition of farming eels in the Americas. It is well documented that American Eels were very important and widely used for sustenance, reverence, and practical purposes by Aboriginal peoples in prehistoric and historic times (Casselman 2003, MacGregor et al. 2009, Engler-Palma et al. 2013, Miller and Casselman 2014). Throughout the range, yellow and silver eels have also been fished commercially since European colonisation and more recently all life stages (excluding leptocephali) have been fished. The species was once extremely abundant in watersheds and tributaries in two of the largest reservoirs for the species — Lake Ontario and St. Lawrence River system and Mississippi River system — but has gradually declined since the turn of the 20th century, most rapidly from the 1970s to the present (Casselman 2003, MacGregor et al. 2013, Phelps et al. 2014).

Historically, glass eels and elvers have been commercially fished extensively along the Atlantic Coast of the U.S. for striped bass bait to supply farms in Asia (ASMFC 2012). Since 2001 glass eels are only fished in two states: Maine and South Carolina, with Maine greatly dominant in catch and activity (ASMFC 2012). Small yellow eels are still a popular bait fish for large striped bass fishery.

Global FAO catch data for American Eel is available for the period 1950–2011. In the 1950s and early 1960s, reported annual American Eel catch averaged 900 tonnes. This doubled to ~2,000 tonnes per year in the 1970s, after which there has been a gradual decline back to 1950 catch levels in the 2000s. Throughout this period, catch was split relatively evenly between the U.S. and Canada, with small intermittent annual catches of one to 50 tonnes reported by Mexico, the Dominican Republic and Cuba. In 2011, catches of young yellow eels from Mexico (140 t) and the Dominican Republic (72 t) were the highest ever recorded from these countries […]. These catches include all life stages (FAO, 2013).

Historically, commercial harvest of yellow and silver eels in Canada and the U.S. has been approximately equal (MacGregor et al. 2009). From 1950 to 2010, U.S. Atlantic coast landings ranged from approximately 300 t in 1962 to 1,665 t in 1979 (ASMFC 2012). After an initial decline in the 1950s, landings increased to a peak in the 1970s and 1980s in response to higher demand from European food markets. In most regions, landings declined sharply in the 1990s and 2000s following a few years of peak landings. The value of U.S. commercial American Eel landings as estimated by NOAA Fisheries has varied from less than $100,000 (prior to the 1980s) to a peak of $6.4 million in 1997. Total landings value increased through the 1980s and 1990s, dropped in the late 1990s, and increased again in the 2000s. The average harvest along the Atlantic coast of the U.S. from 1980 to 2011 was 672 t. In recent years, over half of the harvest of yellow eels has occurred in the State of Maryland (ASMFC 2013). From 2004 to 2010, average annual harvest was 356 t but increased in 2011 to 529 t while harvest in Canada was 337 t and from Mexico and the Dominican Republic a greatly elevated harvest of 212 t. Total overall harvest of the American eel in 2011 was 1,078 t, with approximately 20% coming from the extreme southern part of the range.

American Eels, both live and frozen, have been exported to principal eel consuming markets in Europe and Asia for decades and consumed very little in North America (Miller and Casselman 2014). Between 1997 and 2007 the U.S. and Canada were globally the first and third most important exporters of frozen eel, together exporting 35% of the global total during this period, and on average 2,500 t per year. Over the last 15 years the U.S. and Canada have also been the first and third most important suppliers of live eels to Europe (all life stages), responsible for nearly 50% of all imports of live eels into the EU, averaging at 450 t a year (Crook 2010, Crook 2011).

Eel farming, which is responsible for over 90% of all *Anguilla* production worldwide (averaging at 280,000 tonnes per year since 2007, (FAO 2013)), is reliant on wild-caught juvenile eels or glass eels, as raising eel larvae to the glass eel stage in captivity has only had limited success as yet (Tanaka et al. 2003). The U.S. and Canada have exported *A. rostrata* glass eels to the principal East Asian eel farming countries/territories in small, irregular quantities for a number of decades. Between 1998 and 2010, live eel fry imports from *A. rostrata* range states into

mainland China and Hong Kong ranged from 0.1 to 10 t per year. However, in 2011 combined imports increased suddenly - from just under 10 t in 2010 to nearly 54 t in 2011 and nearly 28 t in 2012; these high figures have been questioned, however, to date, no other data is available. This sudden change in export quantities coincided with the EU's decision, at the end of 2010 to ban exports of European Eel, which had previously met a demand borne from a decline in *A. japonica* glass eel catches.

In 2012, for the first time in over ten years, Japan also imported live eel fry directly from the U.S. (Crook and Nakamura 2013, Crook in litt. 2013) - web-based advertisements in 2013 indicate that the price for *A. rostrata* glass eels has increased by orders of magnitudes in recent years. Maine and South Carolina are the only two U.S. States that allow commercial fishing of glass eels, however considerable levels of poaching and illegal trade, driven by the ever increasing prices offered for this commodity, have been reported from several States (Anon. 2012). Of the more southerly range of *A. rostrata*, Cuba, the Dominican Republic and Haiti have recently started exporting glass eels to Hong Kong and Korea (according to Asian Customs import data). A U.S.-based Asian-owned company advertises setting up camps along the U.S. coast and in the Caribbean to harvest and export glass eels to Asia (Glass Eel Farm 2012). However, at present only two companies (of 34 companies that applied for permits) are authorized to harvest glass eels in the Dominican Republic and illegal harvesting and trade via Haiti has become an issue of considerable concern to Dominican authorities (Anon. 2013)."

Diseases

No records of OIE-reportable diseases (OIE 2020) were found for *Anguilla rostrata*.

From Froese and Pauly (2020):

"Aeromonosis, Bacterial diseases
Hysterothylacium Infection 7, Parasitic infestations (protozoa, worms, etc.)
Johnstonmawsonia Infection, Parasitic infestations (protozoa, worms, etc.)"

According to Poelen et al. (2014), *Anguilla rostrata* is a host to the following parasites and pathogens: *Proteocephalus macrocephalus, Bothriocephalus claviceps, Paratenuisentis ambiguous, Philometridae, Metascaris canadensis, Thylakodesme propria, Spirocamallanus, Ergasilus celestis, Neoechinorhynchus agilis, Fessisentis vancleavei, Echinorhynchus lateralis, Pomphorhynchus lucyi, Neoechinorhynchus rostratus, Neoechinorhynchus rostratum, Lacistorhynchus tenuis, Gyrodactylus anguillae, Pseudodactylogyrus anguillae, Pseudodactylogyrus bini, Daniconema anguillae, Hysterothylacium cenotae, Stephanostomum tenue, Crepidostomum cornutum, Deropristis inflata, Hemiurus appendiculatus, Alloglossidium corti, Podocotyle atomon, Crepidostomum brevivitellum, Crepidostomum illinoiense, Centrovarium lobotes, Diplostomum flexicaudum, Deropristis hispida, Tubulovesicula pinguis, Lecithochirium grandiporum, Alloglossidium kenti, Azygia longa, Echinorhynchus salmonis, Goezia* sp.*, Paraquimperia tenerrima, Leptorhynchoides thecatus, Neoechinorhynchus cylindratus, Acanthocephalus dirus, Pomphorhynchus* sp.*,* proboscis worm (*Echinorhynchus gadi*), *Echinorhynchus* sp.*, Bothriocephalus scorpii, Contracaecum* sp.*, Microphallus* sp.*, Myxidium* sp.*, Proteocephalus* sp.*, Anguillicola crassus, Diplostomum spathaceum, Derogenes*

varicus, Spiruroidea sp.*, Ascaris* sp.*,* Anguillid perhabdovirus*, Aeromonas salmonicida*, Flesh-eating bacteria (*Aeromonas hydrophila*), *Neoechinorhynchus* sp.*,* and *Brachyphallus crenatus.*

Threat to Humans

From Froese and Pauly (2020):

"Harmless"

3 Impacts of Introductions

From Fuller et al. (2019a):

"Eels in Canada (New Brunswick and Nova Scotia), Connecticut, Florida, Maine, Maryland, Massachusetts, New Jersey, New York, Rhode Island, South Carolina, and Texas have been found to be infected with the Asian eel nematode *Anguicolla crassus* (Sokolowski and Dove, 2006; Aieta and Oliveira, 2009; M. Ray, personal communication). Infection rates of eels varies widely, with locations ranging from 0-76% prevalence and mean infection intensity ranging from 1.0-7.6 worms per eel (Barse and Secor, 1999; Aieta and Oliveira, 2009). This parasite infests the swimbladder (Sokolowski and Dove, 2006), causing retarded growth and maturation, and is fatal to a high percentage of eels. It has also been found to infect small fishes, amphibians, and aquatic insects, which are used as paratenic hosts."

The following information pertains to potential impacts of introduction.

From Marohn et al. (2014):

"This study investigated growth, condition and development of American eels *Anguilla rostrata* that were introduced into a European river to estimate their competitive potential in a non-native habitat. Results demonstrate that *A. rostrata* develops normally in European waters and successfully competes with the native European eel *Anguilla anguilla*. In addition, *A. rostrata* appears to be more susceptible to the Asian swimbladder nematode *Anguillicola crassus* than *A. anguilla* and could support the further propagation of this parasite. Detected differences in fat content and gonad mass between *Anguilla* species are assumed to reflect species-specific adaptations to spawning migration distances. This study indicates that *A. rostrata* is a potential competitor for the native fauna in European fresh waters and suggests strict import regulations to prevent additional pressure on *A. anguilla* and a potential further deterioration of its stock situation."

"The repeatedly observed appearance of significant numbers of *A. rostrata* in German eel surveys (Frankowski et al., 2009; Marohn et al., 2013[…]) is a matter of concern as *A. rostrata* provides a putative competitor for the endangered *A. anguilla* and a possible vector for non-native parasites and diseases."

Anguilla rostrata is regulated in California.

4 History of Invasiveness

The History of Invasiveness category is Data Deficient. *Anguilla rostrata* does have significant trade history and has been stocked outside of its native range. There is documentation of nonnative introductions of *A. rostrata*; however, evidence of impacts of establishment is limited or described as potential.

5 Global Distribution

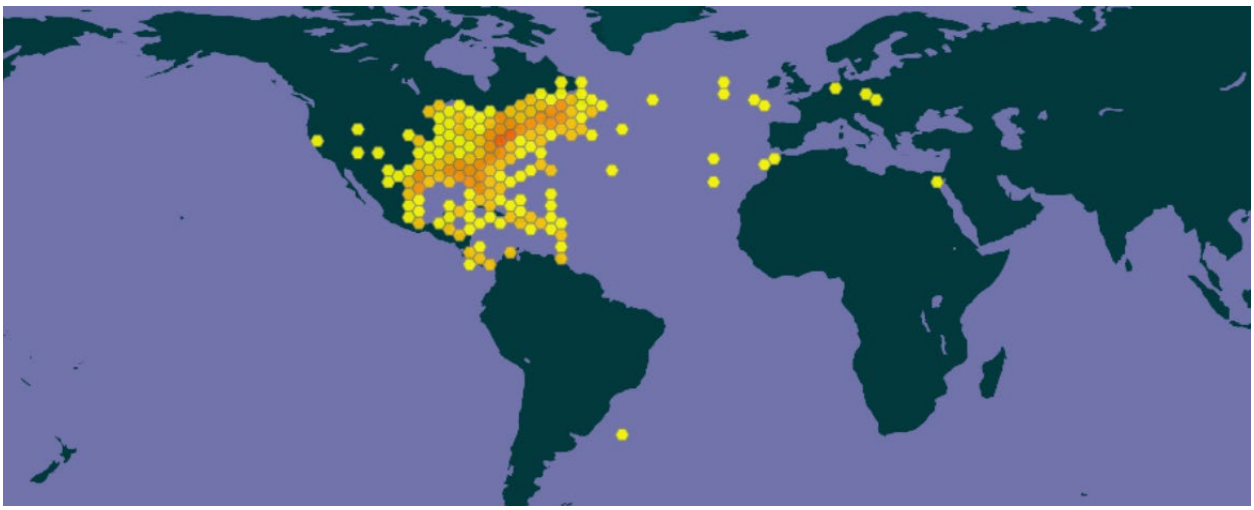

Figure 1. Known global distribution of *Anguilla rostrata*. Observations are reported largely from the eastern half of North America, Central America, and island nations bordering the Caribbean Sea. Additional observations include the North Atlantic Ocean, northern Europe, and the Red Sea. Map from GBIF Secretariat (2020). Locations in Morocco and Czechia will not be included in the climate match as they represent museum specimens and not established populations. Locations off the coast of Egypt and in Germany will not be included as they represent a single specimen observed at each location and no further information could be found to consider it an established population. Locations in California, Utah, and Arizona will not be included in the climate match as they do not represent established populations according to Fuller et al. (2019a, 2019b). Because the climate matching analysis is not valid for marine waters, no marine occurrences were used in the climate matching analysis.

6 Distribution Within the United States

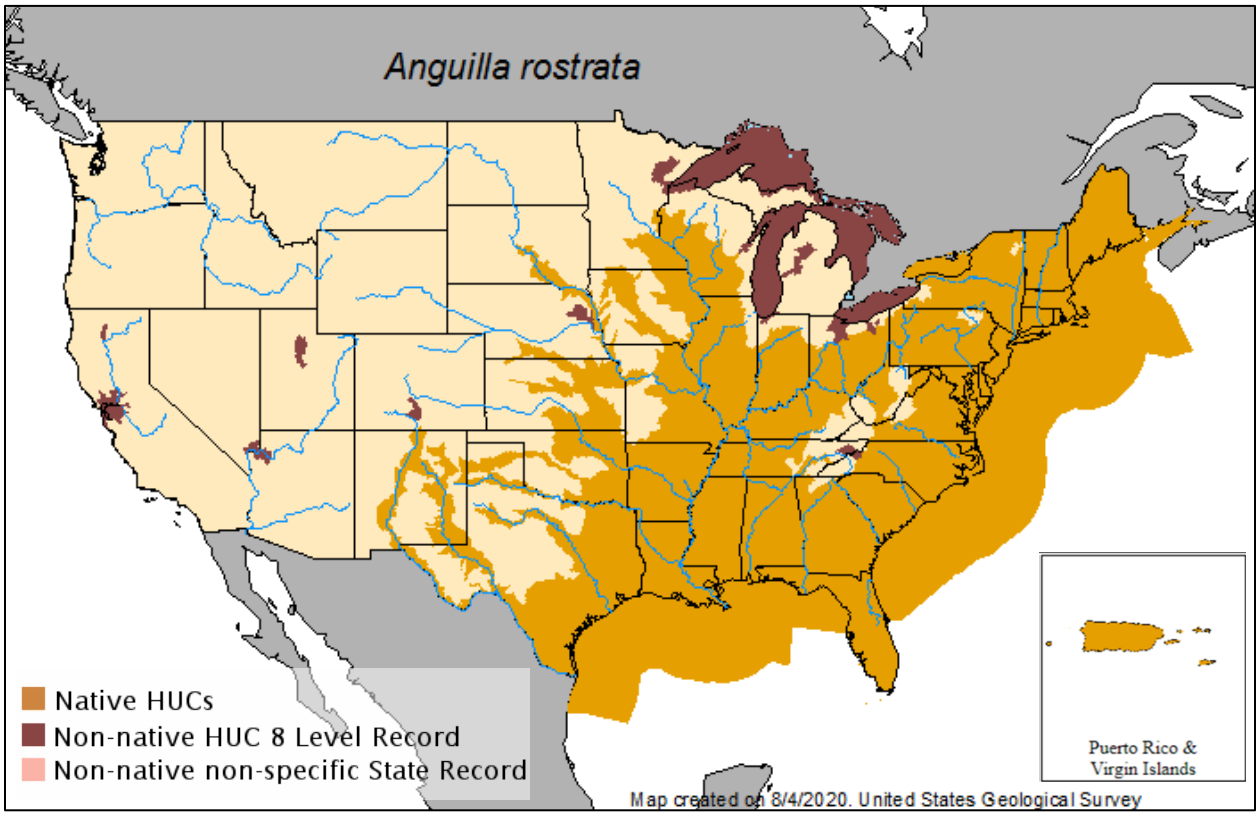

Figure 2. Known distribution of *Anguilla rostrata* in the contiguous United States, Puerto Rico, and the Virgin Islands. Map from Fuller et al. (2019a). Areas shaded in yellow represent the native range of this species, while the areas in red represent nonnative occurrences.

Figure 3. Map of known distribution of *Anguilla rostrata* in the contiguous United States. The native range of this species in the United States is shaded in yellow with nonnative introductions represented by points. Nonnative introductions are found in the Great Lakes region, Tennessee, and in the West. Map from Fuller et al. (2019a). Locations in the West will not be used in the climate matching as they do not represent established populations according to Fuller et al. (2019a, 2019b).

7 Climate Matching

Summary of Climate Matching Analysis

The climate match for *Anguilla rostrata* in the contiguous United States is generally very high. High match is found throughout the native range of this species (most States bordering or east of the Mississippi River), as well as surrounding areas in the central States. A small area of low match was found in the Pacific Northwest. Medium match was found in most of the remaining western States. The overall Climate 6 score (Sanders et al. 2018; 16 climate variables; Euclidean distance) for the contiguous United States was 0.744, high. (Scores of 0.103 or greater are classified as high.) Nearly all States received high individual Climate 6 scores. California, Idaho, and Nevada received medium individual Climate 6 scores. Oregon and Washington received low individual scores. All remaining States received high individual Climate 6 scores. The climate match presented here refers only to nonmarine environments where the species can survive.

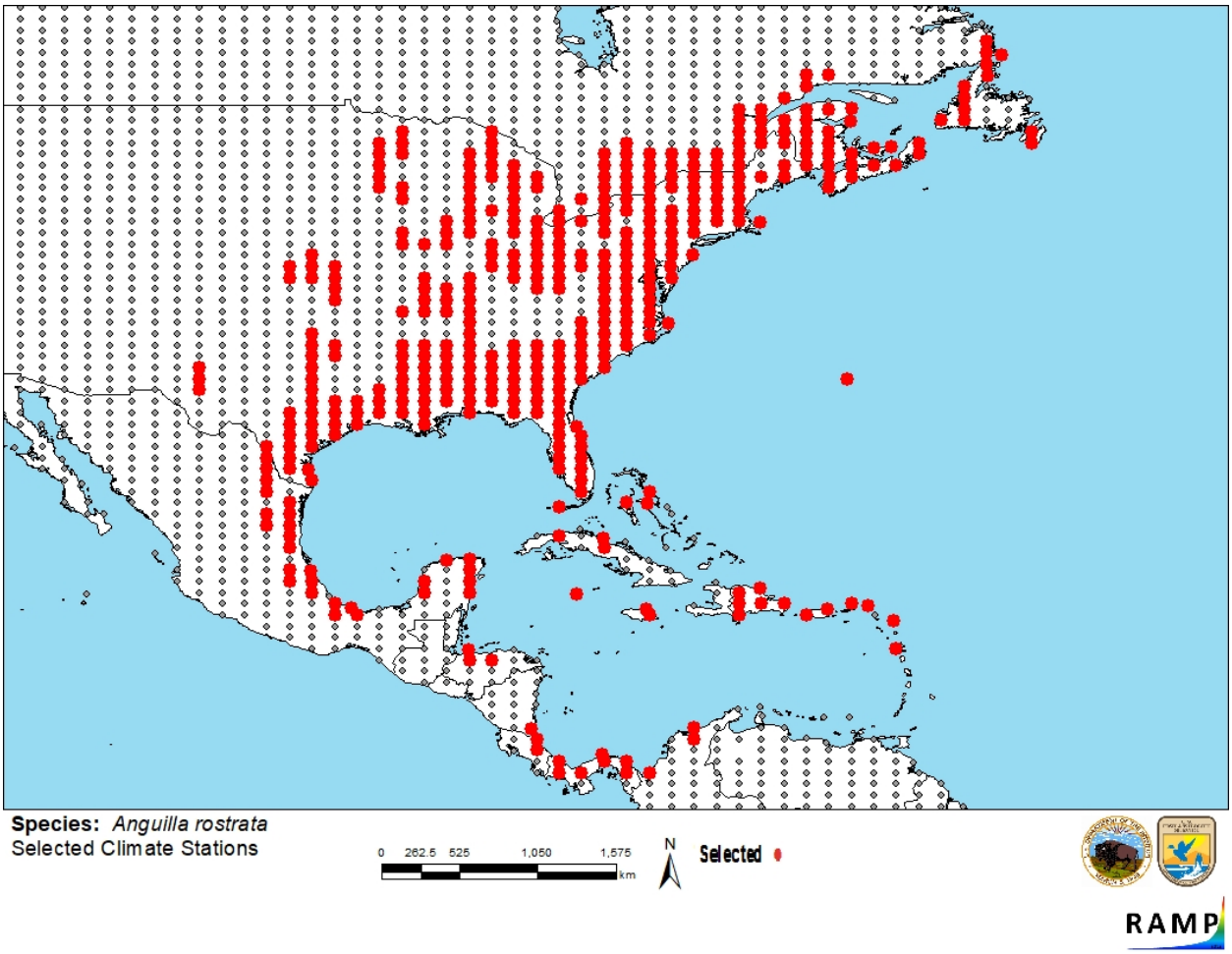

Figure 4. RAMP (Sanders et al. 2018) source map showing weather stations in North, Central, and South America, including among the islands of the Caribbean Sea, selected as source locations (red; Canada, United States, Mexico, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Bahamas, Cuba, Dominican Republic, Jamaica, Puerto Rico, British Virgin Islands, Guadeloupe, Antigua and Barbuda) and non-source locations (gray) for *Anguilla rostrata* climate matching. Source locations from GBIF Secretariat (2020). Selected source locations are within 100 km of one or more species occurrences, and do not necessarily represent the locations of occurrences themselves.

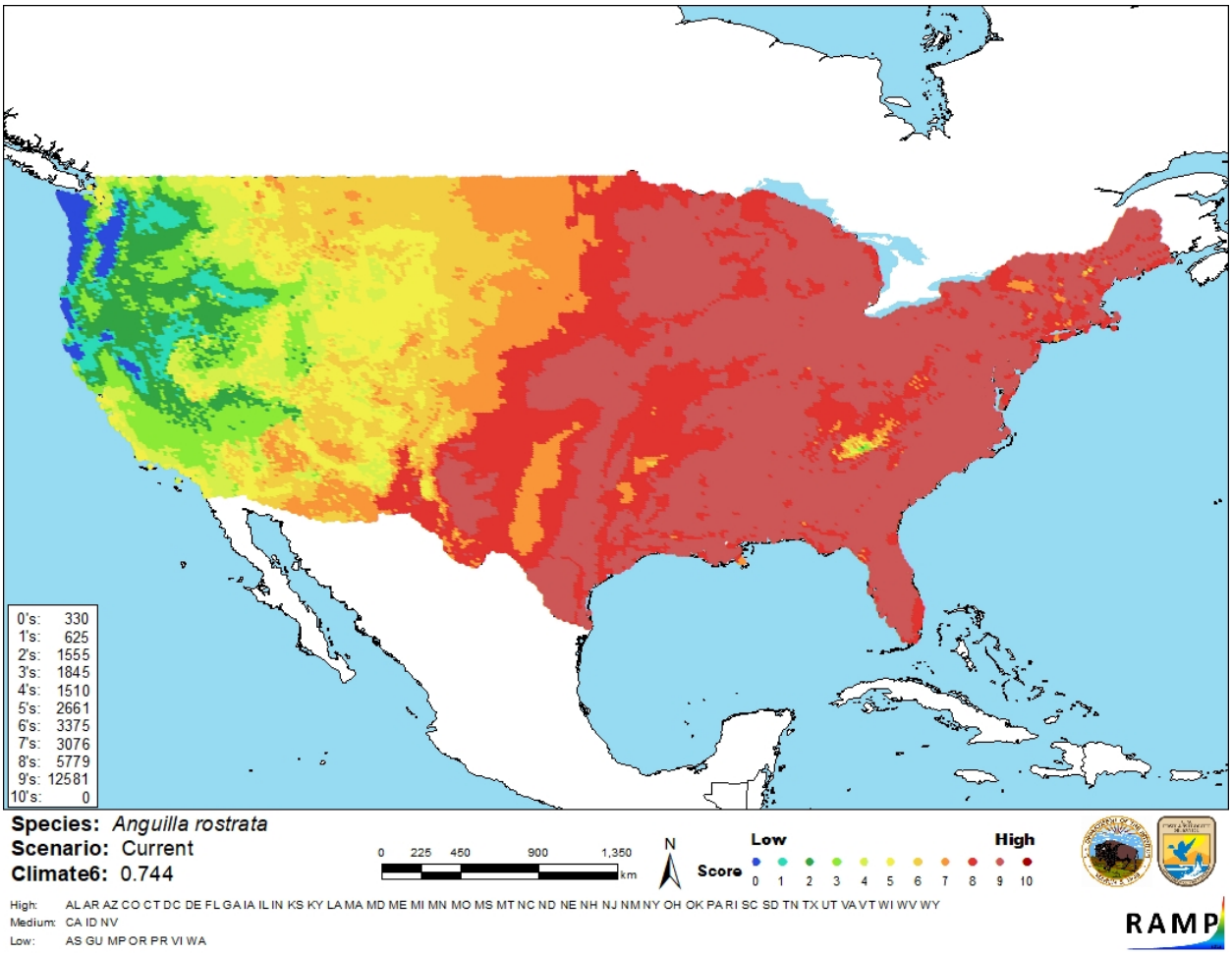

Figure 5. Map of RAMP (Sanders et al. 2018) climate matches for *Anguilla rostrata* in the contiguous United States based on source locations reported by GBIF Secretariat (2020). Counts of climate match scores are tabulated on the left. 0/Blue = Lowest match, 10/Red = Highest match.

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

Climate 6: (Count of target points with climate scores 6-10)/ (Count of all target points)	Overall Climate Match Category
0.000≤X≤0.005	Low
0.005<X<0.103	Medium
≥0.103	High

8 Certainty of Assessment

The biology and ecology of *Anguilla rostrata* are well documented and information about their distribution is readily available. *A. rostrata* is native to large portions of the eastern half of the United States and coastal areas of the Atlantic Ocean. This species has been introduced outside of its native range in multiple locations in the United States and internationally; however,

information on established introduced populations is lacking and impacts from introductions are mostly potential. This species migrates between marine and freshwater environments. Because not all locations in the United States are conducive to such migration, inland establishment of this species may be limited according to habitat connectivity. The certainty of assessment is Low.

9 Risk Assessment

Summary of Risk to the Contiguous United States

The American Eel, *Anguilla rostrata*, is a species of catadromous eel native to Atlantic coastal waters and inland rivers of portions of North, Central, and South American countries that border the Atlantic Ocean, Gulf of Mexico, and Caribbean Sea, including the United States. This species has significant trade history as a food fish and as bait both domestically and internationally. *A. rostrata* is regulated in California. There is documentation of introductions and stocking of this species outside of its native range in the United States and internationally. Limited information is available on impacts of introduction. This species can transmit the nematode *Anguillicola crassus* and has the potential to impact the European eel *Anguilla anguilla* where the American eel is established in Europe, as well as transmit other parasites and pathogens to native species. The history of invasiveness is Data Deficient. The overall climate match was High for the contiguous United States, and a high match was found in most eastern (includes the native range of this species) and central States. However, since this species cannot reproduce in non-marine environments, the climate match is only for areas where the species may be able to survive, but not reproduce. This species migrates between marine and freshwater environments. Because not all locations in the United States are conducive to such migration, inland establishment of this species may be limited according to habitat connectivity. The certainty of assessment is Low. The overall risk assessment category for *Anguilla rostrata* is Uncertain.

Assessment Elements

- **History of Invasiveness (Sec. 4): Data Deficient**
- **Overall Climate Match Category (Sec. 7): High**
- **Certainty of Assessment (Sec. 8): Low**
- **Remarks, Important additional information:** This species is catadromous, requires marine environments to reproduce.
- **Overall Risk Assessment Category: Uncertain**

10 Literature Cited

Note: The following references were accessed for this ERSS. References cited within quoted text but not accessed are included below in Section 11.

California Department of Fish and Wildlife. 2019. Restricted species laws and regulations manual. Available: https://wildlife.ca.gov/Conservation/Invasives/Regulations (November 2020).

[FAO] Fisheries and Agriculture Organization of the United Nations. 2020. Database on introductions of aquatic species. Rome: FAO. Available: http://www.fao.org/fi/website/FISearchAction.do (December 2020).

Fricke R, Eschmeyer WN, van der Laan R, editors. 2021. Catalog of fishes: genera, species, references. California Academy of Science. Available: http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp (August 2021).

Froese R, Pauly D, editors. 2020. *Anguilla rostrata* (Lesueur, 1817). FishBase. Available: https://www.fishbase.de/summary/Anguilla-rostrata.html (December 2020).

Fuller P, Nico L, Neilson M, Dettloff K, Sturtevant R. 2019a. *Anguilla rostrata* (Lesueur, 1817): Gainesville, Florida: U.S. Geological Survey, Nonindigenous Aquatic Species Database. Available: https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=310 (December 2020).

Fuller P, Nico L, Neilson M, Dettloff K, Sturtevant R. 2019b. *Anguilla rostrata* (Lesueur, 1817). Gainesville, Florida: U.S. Geological Survey, Nonindigenous Aquatic Species Database, and Ann Arbor, Michigan: NOAA Great Lakes Aquatic Nonindigenous Species Information System. Available: https://nas.er.usgs.gov/queries/greatLakes/FactSheet.aspx?SpeciesID=310&Potential=N&Type=0&HUCNumber=DGreatLakes (December 2020).

GBIF Secretariat. 2020. GBIF backbone taxonomy: *Anguilla rostrata* (Lesueur, 1817). Copenhagen: Global Biodiversity Information Facility. Available: https://www.gbif.org/species/5212956 (December 2020).

[ITIS] Integrated Taxonomic Information System. 2020. *Anguilla rostrata* (Lesueur, 1817). Reston, Virginia: Integrated Taxonomic Information System. Available: https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=161127#null (September 2020).

Jacoby D, Casselman J, DeLucia M, Gollock M. 2017. *Anguilla rostrata* (amended version of 2014 assessment). The IUCN Red List of Threatened Species 2017: e.T191108A121739077. Available: https://www.iucnredlist.org/species/191108/121739077 (September 2020).

Marohn L, Prigge E, Hannel R. 2014. Introduced American eels *Anguilla rostrata* in European waters: life-history traits in a non-native environment. Journal of Fish Biology 84:1740–1747.

[OIE] World Organisation for Animal Health. 2020. OIE-listed diseases, infections and infestations in force in 2020. Available: http://www.oie.int/animal-health-in-the-world/oie-listed-diseases-2020/ (December 2020).

Poelen JH, Simons JD, Mungall CJ. 2014. Global Biotic Interactions: an open infrastructure to share and analyze species-interaction datasets. Ecological Informatics 24:148–159.

Sanders S, Castiglione C, Hoff M. 2018. Risk Assessment Mapping Program: RAMP. Version 3.1. U.S. Fish and Wildlife Service.

[USFWS] U.S. Fish and Wildlife Service. 2019. The American Eel. Available: https://www.fws.gov/northeast/americaneel/ (September 2020).

Xiong W, Shen C, Wu Z, Lu H, Yan Y. 2017. A brief overview of known introductions of non-native marine and coastal species into China. Aquatic Invasions 12:109–115.

11 Literature Cited in Quoted Material

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.

Albert V, Jonsson B, Bernatchez L. 2006. Natural hybrids in Atlantic eels (*Anguilla anguilla*, *Anguilla rostrata*): evidence for successful reproduction and fluctuating abundance in space and time. Molecular Ecology 15:1903–1916.

Aieta AE, Oliveira K. 2009. Distribution, prevalence, and intensity of the swim bladder parasite *Anguillicola crassus* in New England and eastern Canada. Diseases of Aquatic Organisms 84:229–235.

Anon. 2013. Pescan y sacan del pais a las anguilas de manera clandestina. Diario Libre.

Anon. 2012. Maine's Elvers—Transparent Gold. The Economist Print Edition.

[ASMFC] Atlantic States Marine Fisheries Commission. 2013. Proceedings of the Atlantic States Marine Fisheries Commission, American eel Management Board. Arlington.

[ASMFC] Atlantic States Marine Fisheries Commission. 2012. American eel benchmark stock assessment. Arlington, Virginia: Atlantic States Marine Fisheries Commission. Stock Assessment Report 12-01

Avise JC, Nelson WS, Arnold J, Koehn RK, Williams GC, Thorsteinsson V. 1990. The evolutionary genetic status of Icelandic eels. Evolution 44:1254–1262.

Baensch HA, Riehl R. 1995. Aquarien Atlas. Band 4. Germany: Mergus Verlag GmbH, Verlag für Natur- und Heimtierkunde.

Baras E, Jeandrain D, Serouge B, Philippart JC. 1998. Seasonal variations in time and space utilization by radio-tagged yellow eels *Anguilla anguilla* (L.) in a small stream. Hydrobiologia (371–372):187–198.

Barse AM, Secor DH. 1999. An exotic nematode parasite of the American eel. Fisheries 24(2):6–10.

Becker GC. 1983. Fishes of Wisconsin. Madison: University of Wisconsin Press.

Bigelow HB, Schroeder WC. 1953. Fishes of the Gulf of Maine. Fishery Bulletin 53:1–577.

Boëtius J. 1980. Atlantic Anguilla. A presentation of old and new data of total numbers of vertebrae with special reference to the occurrence of *Anguilla rostrata* in Europe. Dana (Charlottenlund):93–112.

Busch WN, Davies DH, Nepszy SJ. 1977. Establishment of white perch, *Morone americana*, in Lake Erie. Journal Fisheries Research Board Canada 34(7):1039–1041.

Casselman JM. 2003. Dynamics of resources of the American eel, *Anguilla rostrata*: declining abundance in the 1990s. Pages 255–274 in Aida K, Tsukamoto K, Yamauchi K, editors. Eel Biology. Tokyo: Springer-Verlag.

Cochran PA. 1981. An unusually small American eel (*Anguilla rostrata*) from the Lake Superior drainage. Canadian Field-Naturalist 95:97–98.

[COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2006. COSEWIC assessment and status report on the American eel *Anguilla rostrata* in Canada. Ottawa: Committee on the Status of Endangered Wildlife in Canada.

Crook V. 2010. Trade in *Anguilla* species, with a focus on recent trade in European Eel *A. anguilla*. In TRAFFIC: Report prepared for the European Commission. Available athttps://portals.iucn.org/library/node/9667/ (February 2014).

Crook V. 2011. Trade in European Eels: Recent developments under CITES and the EU Wildlife Trade Regulations. TRAFFIC Bulletin 23(2):71–74.

Crook V, Nakamura M. 2013. Glass eels: Assessing supply chain and market impacts of a CITES listing on Anguilla species. TRAFFIC Bulletin 25:24–30.

Engler-Palma C, VanderZwaag DL, Apostle R, Castonguay M, Dodson JJ, Feltes E, Norchi C, White R. 2013. Sustaining American eels: A slippery species for science and governance. Journal of International Wildlife Law and Policy 16:128–169.

Facey DE, Van den Avyle MJ. 1987. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) - American eel. U.S. Fish and Wildlife Service Biological Report 82(11.74).

Fahay MP. 1978. Biological and fisheries data on American eel, *Anguilla rostrata* (Lesueur). United States National Oceanic and Atmospheric Administration, Northeast Fisheries Center, Sandy Hook Laboratory Technical Series Report 17.

[FAO] Fisheries and Agriculture Organization of the United Nations. 2013. Database on Capture and Aquaculture Production (1950-2011) and Fisheries Commodities Production and Trade (1976-2009). (August 2013). [Source material did not give full citation for this reference.]

Frankowski J, Jennerich S, Schaarschmidt T, Ubl C, Jurss K, Bastrop R. 2009. Validation of the occurrence of the American eel *Anguilla rostrata* (Lesueur, 1817) in free-draining European inland waters. Biological Invasions 11:1301–1309.

Fukano KG, Gowing H, Hansen MJ, Allison LN. 1964. Introduction of exotic fish into Michigan. Ann Arbor: Michigan Department of Conservation, Institute of Fisheries Research.

Gerking SD. 1945. Distribution of the fishes of Indiana. Investigations of Indiana Lakes and Streams 3:1–137.

Glass Eel Farm. 2012. Available: http://www.glasseelfarm.com/english_site. [Source material did not give full citation for this reference.]

Goode GB. 1884. The fisheries and fishery industries of the United State. Washington, DC: Government Printing Office.

Greenfield DW, Thomerson JE. 1997. Fishes of the continental waters of Belize. Florida: University Press of Florida.

Hardy JD Jr. 1978. Development of fishes of the Mid-Atlantic Bight: An atlas of egg, larval, and juvenile stages. Volume II – Anguillidae thorough Syngnathidae. U.S. Department of the Interior, Fish and Wildlife Service.

Hill LG. 1969. Reactions of the American eel to dissolved oxygen tensions. The Texas Journal of Science 20(4):305–313.

ICES. 2012. Report of the 2012 Session of the Joint EIFAAC/ICES Working Group on Eels. ICES CM 2012/ACOM:18. Available: http://ices.dk/sites/pub/Publication Reports/Expert Group Report/acom/2012/WGEEL/wgeel_2012_FAO.pdf/ (February 2014).

[IGFA] International Game Fish Association. 1991. World record game fishes. Florida: International Game Fish Association.

Jessop BM. 1987. Migrating American eels in Nova Scotia. Transactions of the American Fisheries Society 116(2):161–170.

Lee DS. 1980. *Anguilla rostrata* (Lesueur), American eel. Page 59 in Lee DS, Gilbert CR, Hocutt CH, Jenkins RE, McAllister DE, Stauffer JR Jr, editors. Atlas of North American freshwater fishes. Raleigh: North Carolina State Museum of Natural History.

Lookabaugh PS, Angermeier PL. 1992. Diel patterns of American eel, *Anguilla rostrata*, in the James River Drainage, Virginia. Journal of Freshwater Ecology 7(4):425–431.

MacGregor R, Casselman JM, Allen WA, Haxton T, Dettmers JM, Mathers A, LaPan S, Pratt TC, Thompson P, Stanfield M, Marcogliese L, Dutil JD. 2009. Natural heritage, anthropogenic impacts, and biopolitical issues related to the status and sustainable management of American eel: A retrospective analysis and Management perspective at the population level. American Fisheries Society Symposium 69:713–739.

MacGregor R, Casselman J, Greig L, Dettmers J, Allen WA, McDermott L, Haxton T. 2013. DRAFT recovery strategy for the American Eel (*Anguilla rostrata*) in Ontario. Peterborough: Ontario Recovery Strategy Series.

Mandrak NE. 2009. Fish fauna of Lake Superior: past, present, and future. Pages 645–663 in Munawar M, Munawar IF, editors. State of Lake Superior. East Lansing: Michigan State University Press.

Marohn L, Prigge E, Hanel R. 2013. Escapement success of silver eels from a German river system is low compared to management-based estimates. Freshwater Biology 59:64–72.

McCosker JE. 1989. Freshwater eels (family Anguillidae) in California: current conditions and future scenarios. California Fish and Game 75:4–10.

Meffe GK, Sheldon AL. 1988. The influence of habitat structure on fish assemblage composition in southeastern blackwater streams. American Midland Naturalist 120(2):225–240.

Minckley WL. 1973. Fishes of Arizona. Arizona Fish and Game Department. Pheonix, Arizona: Sims Printing Company.

Miller RR. 2005. Freshwater fishes of México. Chicago: The University of Chicago Press.

Miller MJ, Casselman JM. 2014. The American eel: A fish of mystery and sustenance for humans. Page 155 in Tsukamoto K, Kuroki M, editors. Eels and humans, humanity and the sea. Japan: Springer.

Milner JW. 1874. Report on the propagation of the shad (*Alosa sapidissima*) and its introduction into new waters by the U.S. Fish Commissioner in 1873. Part XIX Report of the Commissioner of Fish and Fisheries for 1872 and 1873: 419–451.

[OBIS] Ocean Biogeographic Information System. 2006. OBIS-extracted Depth Data. Available: www.iobis.org (July 2006).

Ogden JC. 1970. Relative abundance, food habits, and age of the American eel, *Anguilla rostrata* (Lesueur), in certain New Jersey streams. Transactions of the American Fisheries Society 99:54–59.

Page LM, Burr BM. 1991. A field guide to freshwater fishes of North America north of Mexico. The Peterson Field Guide Series 42. Boston: Houghton Mifflin Company.

Page LM, Burr BM. 2011. A field guide to freshwater fishes of North America north of Mexico. Boston: Houghton Mifflin Harcourt.

Phelps QE, Ridings JW, Herzog DP. 2014. American eel population characteristics in the Upper Mississippi River. American Midland Naturalist 171:165–171.

Popov BH, Low JB. 1953. Game, fur animal, and fish introductions into Utah. Misc. Salt Lake City: Utah State Department of Fish and Game. Publication 4.

Rinne JN. 1995. The effects of introduced fishes on native fishes: Arizona, Southwestern United States. Pages 149–159 in Philipp DP, Epifano JM, Marsden JE, Claassen JE, Wolotina RJ Jr, editors. Protection of aquatic diversity. Proceedings of the World Fisheries Congress, Theme 3. New Delhi, India: Oxford & IBH Publishing Company.

Royal Ontario Museum Fish Collections. 2011. Royal Ontario Museum fish collections - *Anguilla rostrata*.

Schmidt J. 1925. The breeding places of the eel. Rep. Smithson. Inst. 1924:279–316.

Scott WB, Crossman EJ. 1973. Freshwater fishes of Canada. Ottawa, Ontario: Fisheries Research Board of Canada. Bulletin 184.

Scott WB, Scott MG. 1988. Atlantic fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences 219:1–731.

Shebley WH. 1917. History of the introduction of food and game fishes into the waters of California. California Fish and Game 3:3–12.

Sheldon WW. 1974. Elver in Maine: techniques of locating, catching, and holding. Augusta: Maine Department of Marine Resources.

Shute PW, Etnier DA. 2000. Southeastern fishes council regional reports - 2000. Region III - North-Central.

Sigler FF, Miller RR. 1963. Fishes of Utah. Salt Lake City: Utah Department of Fish and Game.

Simon TP. 1999. Assessment of Balon's reproductive guilds with application to Midwestern North American freshwater fishes. Pages 97–121 in Simon TL, editor. Assessing the sustainability and biological integrity of water resources using fish communities. Boca Raton, Florida: CRC Press.

Smith CL. 1997. National Audubon Society field guide to tropical marine fishes of the Caribbean, the Gulf of Mexico, Florida, the Bahamas, and Bermuda. New York: Alfred A. Knopf.

Smith DG. 1968. The occurrence of larvae of the American eel, *Anguilla rostrata*, in the Straits of Florida and nearby areas. Bulletin of Marine Science 18(2):280–293.

Smith HM. 1896. A review of the history and results of the attempts to acclimatize fish and other water animals in the Pacific states. Pages 379–472 in Bulletin of the U.S. Fish Commission, Volume XV, for 1895.

Sokolowski MS, Dove ADM. 2006. Histopathological examination of wild American eels infected with *Anguillicola crassus*. Journal of Aquatic Animal Health 18:257–262.

Tanaka H, Kagawa H, Ohta H, Unuma T, Nomura K. 2003. The first production of glass eel in captivity: fish reproductive physiology facilitates great progress in aquaculture. Fish Physiology and Biochemistry 28:493–497.

Trautman MB. 1981. The fishes of Ohio. Columbus: Ohio State University Press.

[USFWS] U.S. Fish and Wildlife Service. 2006. The American Eel: *Anguilla rostrata*. Available: http://www.fws.gov/northeast/ameel/facts.html (May 2011).

Van den Avyle MJ. 1984. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic)- American eel. U.S. Fish and Wildlife Service. FWS/OBS 82(11.24).

Wenner CA. 1978. Anguillidae. In Fischer W, editor. FAO species identification sheets for fishery purposes. West Atlantic (Fishing Area 31). Rome.

Williamson GR, Tabeta O. 1991. Search for Anguilla eels on the west coast of North America and on the Aleutian and Hawaiian Islands. Japanese Journal of Ichthyology 38(3):315–317.

Zuckerman LD, Behnke RJ. 1986. Introduced fishes in the San Luis Valley, Colorado. Pages 435–452 in Stroud RH, editor. Fish culture in fisheries management. Proceedings of a symposium on the role of fish culture in fisheries management at Lake Ozark, MO, March 31-April 3, 1985. Bethesda, Maryland: American Fisheries Society.