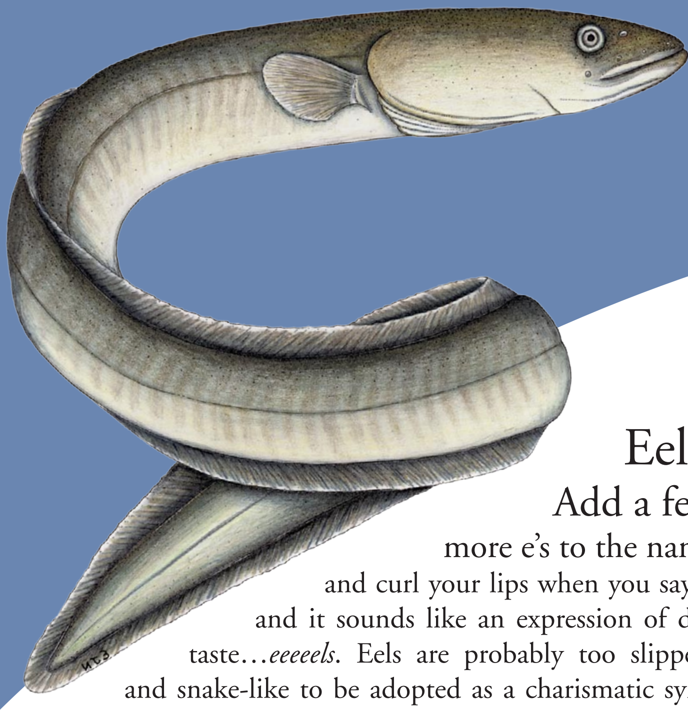
American Eels



Restoring a Vanishing Resource in the Gulf of Maine

Eels.
Add a few more e's to the name and curl your lips when you say it and it sounds like an expression of distaste…*eeeeels*. Eels are probably too slippery and snake-like to be adopted as a charismatic symbol of an environmental movement. Yet the American eel (*Anguilla rostrata*) may be in trouble for some of the same reasons that Atlantic salmon are endangered and many North Atlantic commercial fisheries are declining: habitat loss and degradation, water quality, overfishing, and climate change. In some cases, disregard for eels has led to the complete slaughter of mature eels on their spawning migration, because their only downstream path is through turbines of hydroelectric dams.

American eels have a complex life cycle that makes them vulnerable to environmental change and difficult to conserve and protect. There is concern for the American eel throughout its range from Greenland to South America. Several long-term datasets indicate that numbers of juveniles and young adults have plummeted in many areas of the species' range during the last two decades. Several agencies are working on this problem, led by the Atlantic States Marine Fisheries Commission (ASMFC), which produced a comprehensive eel management plan in 2000 and has since provided updates on how the plan is being implemented and addresses emerging concerns. In 2006, ASMFC completed a stock assessment for American eel that concluded that the abundance of eels has declined in the last two decades and is at or near record low levels.

In 2004, the ASMFC recommended that the United States Fish and Wildlife Service (USFWS) and National Marine Fisheries Service consider protecting the Atlantic coastal stock of American eels. The USFWS agreed to conduct a formal review, sharing concern about the apparent decline of eel populations. Concurrently, the Committee on the Status of Endangered Wildlife in Canada, the Great Lakes Fishery Commission, and the ASMFC also reviewed the status of the American eel and considered management and recovery options. After a comprehensive status review, the USFWS published its 12-month finding in February 2007, concluding that the species should not be protected under the Endangered Species Act (ESA). USFWS biologist Heather Bell stated, "The eel population as a whole shows significant resiliency. If we look at eels over time, we see fluctuations in the population numbers, so a decreasing number of eels right now does not necessarily forecast an irreversible trend." Nevertheless, the USFWS recognized that American eels have declined or been extirpated from portions of their native range, and though eels may not meet the criteria for listing under the ESA, the USFWS will continue to work with other agencies to protect and restore the species. The American eel presents challenges to conservation because its range spans political boundaries and habitats traditionally managed by different agencies, forcing managers to think broadly and work collaboratively. This publication describes these challenges and focuses on restoration in the Gulf of Maine region.

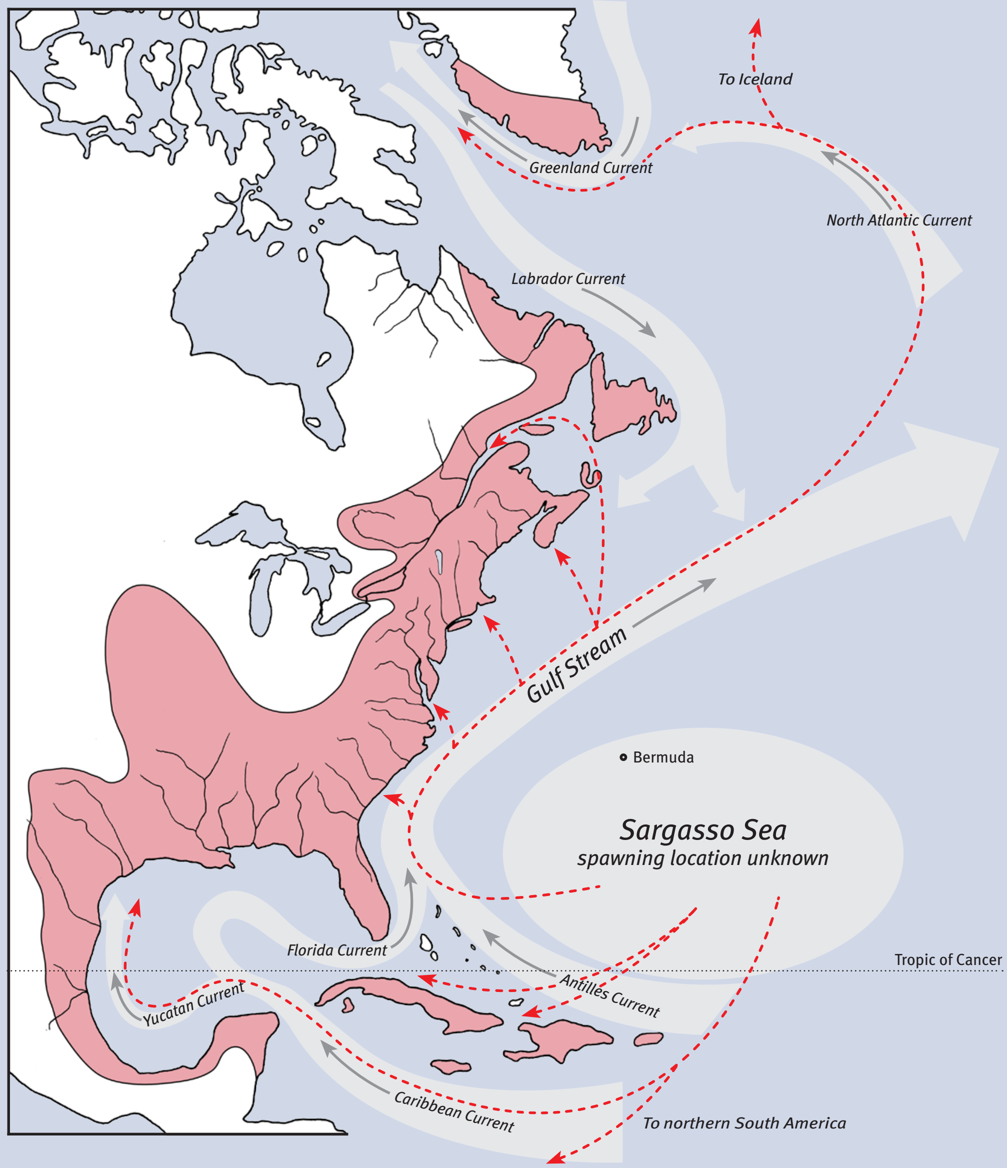
Restoring free-flowing rivers and unrestricted access to a watershed is critical for restoring American eels. Ethan Nedeau

Produced by the Gulf of Maine Council on the Marine Environment, whose mission is to maintain and enhance environmental quality in the Gulf to allow for sustainable resource use by existing and future generations.

Gulf of Maine Council on the Marine Environment

EEL MIGRATION AND LIFE CYCLE

American eels spawn somewhere in the Sargasso Sea east of the Bahamas and south of Bermuda. Eggs and larvae become entrained in ocean currents and are transported to continents. The Antilles Current and Caribbean Current likely carry larvae toward northern South America, Central America, the Gulf of Mexico, and the Caribbean islands. The Antilles Current may also carry larvae toward the Gulf Stream, which transports eels toward North America's eastern seaboard or on lengthy oceanic voyage into the North Atlantic region including Iceland and Greenland. Even more amazing than the largely passive transport of eels toward the continent is the active migration of silver eels back to the spawning area as many as 30-40 years later.

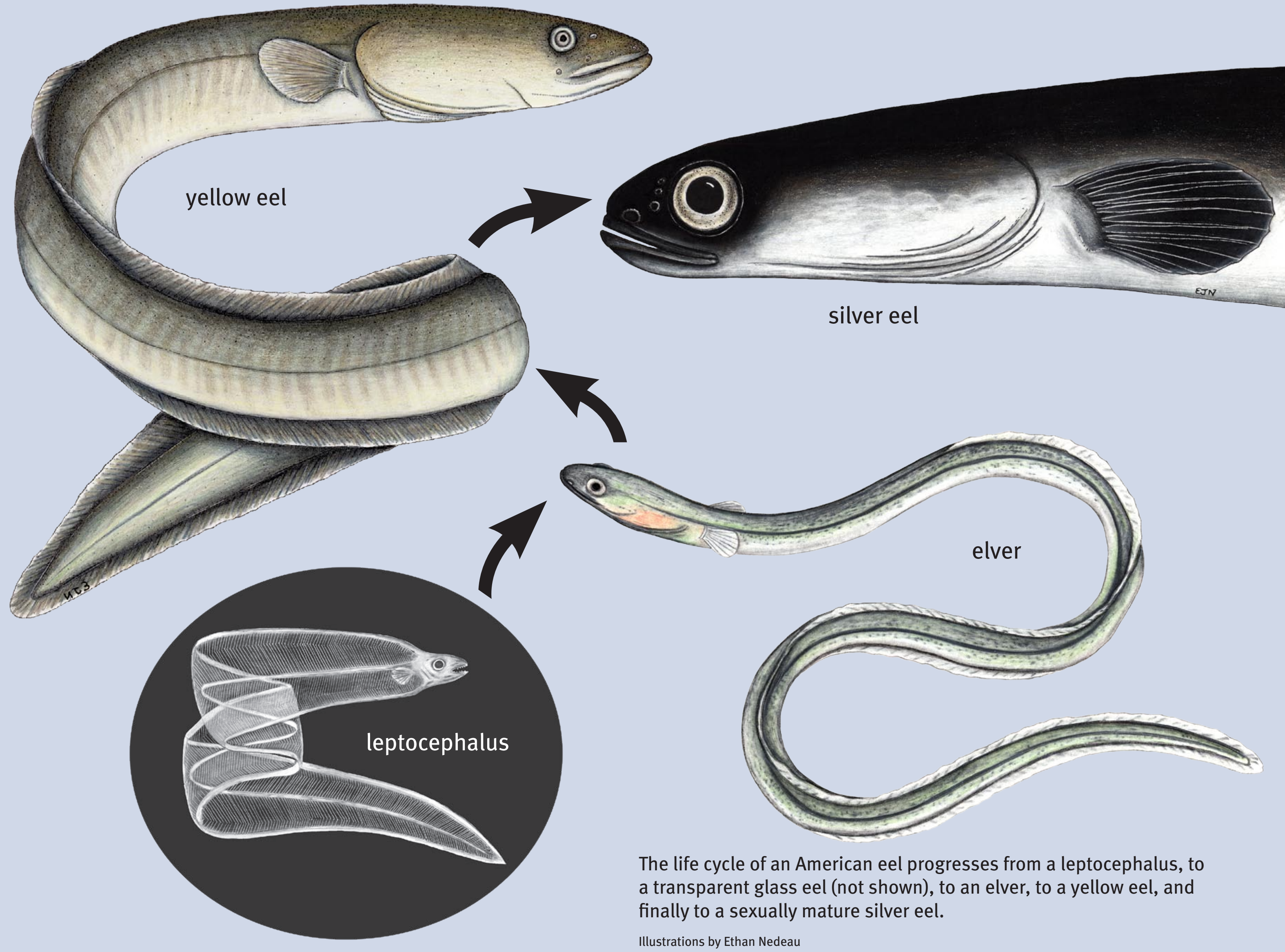


BIOLOGY OF EELS

The American eel is the only catadromous species in the Gulf of Maine. Catadromous species spend most of their lives in fresh or brackish water but spawn in the ocean. Each winter, spawning eels congregate somewhere in the large Sargasso Sea in the western Atlantic Ocean east of the Bahamas and south of Bermuda. They represent a single breeding population, meaning that eels from South America, Greenland, and anywhere in between may breed with each other. Thus, there are no distinct watershed or regional "stocks" as there are for anadromous species such as Atlantic salmon. It is not known if there is a relationship between parental freshwater habitat and drainages colonized by their offspring. Offspring must be capable of surviving in South American streams or icy waters of Greenland, depending on where currents take them.

Spawning habits remain a mystery; the depth and location of spawning is not known and scientists have never observed spawning behavior in the wild. Fecundity depends on the size of the eel, and large females may produce over ten million eggs. Eggs hatch into larvae called leptocephali, which are transparent and shaped like a willow leaf. Ocean currents—the Gulf Stream, Antilles Current, and Florida Current—help transport larvae toward the North American continent. The larval stage may last for over a year, during which time the larvae grow as long as 60 millimeters (2.4 inches) in length and may be transported thousands of miles.

Leptocephali metamorphose into a more recognizably eel-like form called glass eels, so named because they lack pigmentation. Glass eels swim toward coastal areas, and once they reach estuaries, they develop pigmentation and are known as elvers. Glass eels are generally 45-70 millimeters (1.8-2.8 inches) long and elvers are 65-100 millimeters (2.6-3.9 inches) long. In the Gulf of Maine, migration of glass eels and elvers toward the coast occurs mainly from April to July, though some will migrate into early fall. Elvers swim up tidal



The life cycle of an American eel progresses from a leptocephalus, to a transparent glass eel (not shown), to an elver, to a yellow eel, and finally to a sexually mature silver eel.

Illustrations by Ethan Nedeau

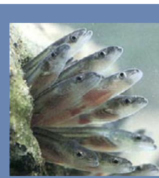
rivers during flood tides and retreat to the bottom as tides ebb. Older juveniles are strong swimmers capable of ascending rivers and navigating small barriers. It may take several years for eels to migrate up rivers, during which time they may travel hundreds of miles.

As elvers grow they become known as yellow eels (Maine statute defines an elver as an American eel that is less than 6 inches in length). Yellow eels may spend six to 30+ years in freshwater. Yellow eels are common in estuaries, rivers and lakes around the Gulf of Maine, though are not frequently caught by anglers because eels are active primarily at night. They prey on or scavenge aquatic invertebrates, amphibians, and fish. In turn, large predators such as bass, lake trout, fish-eating birds, and mammals may eat them.

Eels do not become recognizably male or female until the yellow eel stage. In northern latitudes, a large proportion of yellow eels are female, particularly those that reside in freshwater habitats. In the St. Lawrence watershed, nearly all adult eels are female. In southern latitudes, a greater proportion of adult eels are male. There is evidence that more eels will become male in high-density populations. Females may attain lengths of nearly 130 cm (50 inches). The largest females come from northern areas, particularly the St. Lawrence River. Thus, northern areas may contribute a larger proportion of highly fecund breeding females than southern North America.

Yellow eels metamorphose into the final, sexually mature stage of life, called silver eels. Silver eels are metallic blackish-bronze in color, and have enlarged eyes, fat bodies, and a thicker skin than yellow eels. The digestive tract degenerates during metamorphosis, evidence that the seaward migration is a one-way trip. On dark, rainy nights during September to December, most silver eels descend rivers and begin their journey to the Sargasso Sea. Eels spawn only once, so their spawning migration also represents the last stage of their life before dying.

CONCERN ABOUT EELS



There is international concern for the American eel, but perceived population trends are based on a small number of long-term datasets. Since all eels come from a single breeding population and disperse without apparent fidelity to coastal watersheds, declines in some areas are thought to reflect a range-wide decline.

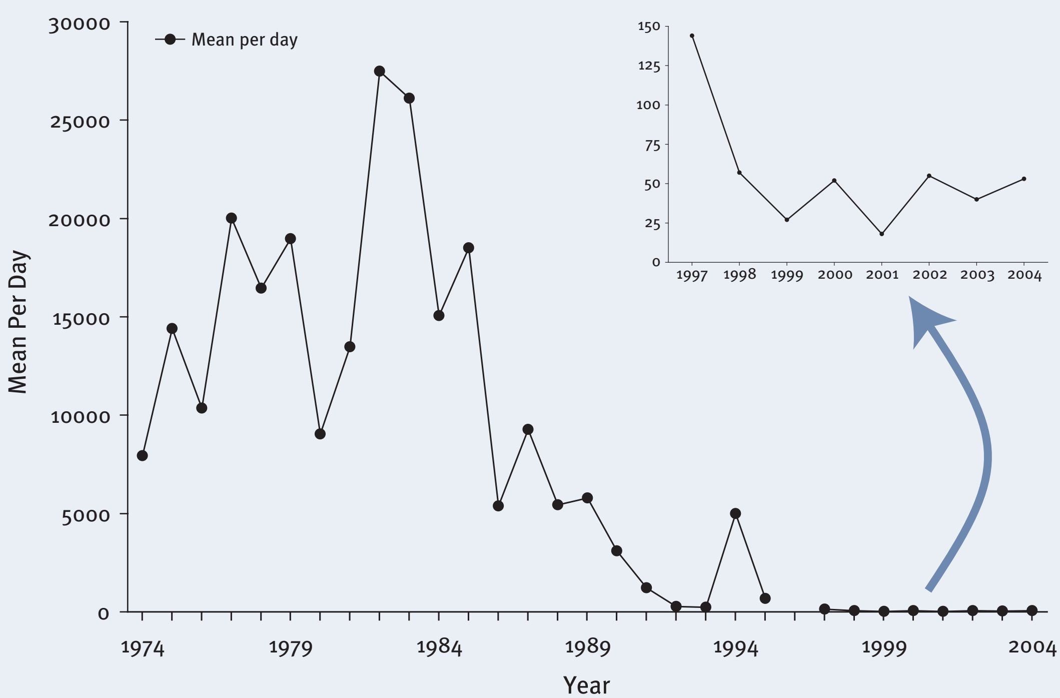
- Castonguay *et al.* (1994) reported an 81-fold decline in yellow eels reaching Lake Ontario from 1985 to 1992, and recent data suggest that this number is declining nearly 25% annually.
- Seven of 16 long-term datasets reviewed by Haro *et al.* (2000) showed significant declines in silver and yellow eels.
- The Stock Assessment Subcommittee of the ASMFC reported that of seven abundance indices for yellow eels, three indices for the mid-1970s to 2004 had declined significantly, four did not show any statistically significant trend, and none had increased (ASMFC 2006).
- From 1994 to 2004, yellow eel indices for Chesapeake Bay and Lake Ontario showed precipitous declines of 50% and 99%, respectively (ASMFC 2006).
- Experts generally agree that American eels have declined in the last two decades to historic low levels and that available data on yellow eel abundance may indicate a species-wide trend that could ultimately result in irreversible population declines (ASMFC 2006).
- The USFWS (2007) determined that while eels have declined or been extirpated in parts of their historic range, the tremendous adaptability, resiliency, and geographic distribution of the species make it unlikely to go extinct; in other words, the population declines are reversible.

It is difficult to demonstrate causal factors for a declining eel population. Scientists can count silver eels leaving a river and estimate the number of elvers that return, but they know very little about the steps in between. Eel reproduction can be erratic and scientists do not understand long-term population dynamics well enough to put recent declines in perspective.

Until recently, population indices were not being measured at all in some areas. Commercial landing data depend on market conditions and fishing intensity, and therefore may not necessarily reflect a declining population. Eels were not on the radar screen of most fisheries management agencies until recently. The ASMFC is leading the effort to standardize monitoring and assess trends from disparate data. Documentation on recent efforts and future projects are available on the ASMFC website, www.asmfc.org.

DECLINING POPULATIONS

This graph shows the number of yellow eels counted at an eel pass installed at the R.H. Saunders Hydroelectric Dam in the upper St. Lawrence River in Cornwall, Ontario. Values are the mean number of animals counted per day during a 31-day peak (mid-summer) migration. This long-term dataset is considered the most reliable indicator of eel recruitment into the Great Lakes. It may indicate recruitment trends for the entire northern range of American eels.



Data used with permission from John M. Casselman, Queen's University, Kingston, Ontario.

THREATS TO EELS

RIVER ACCESS

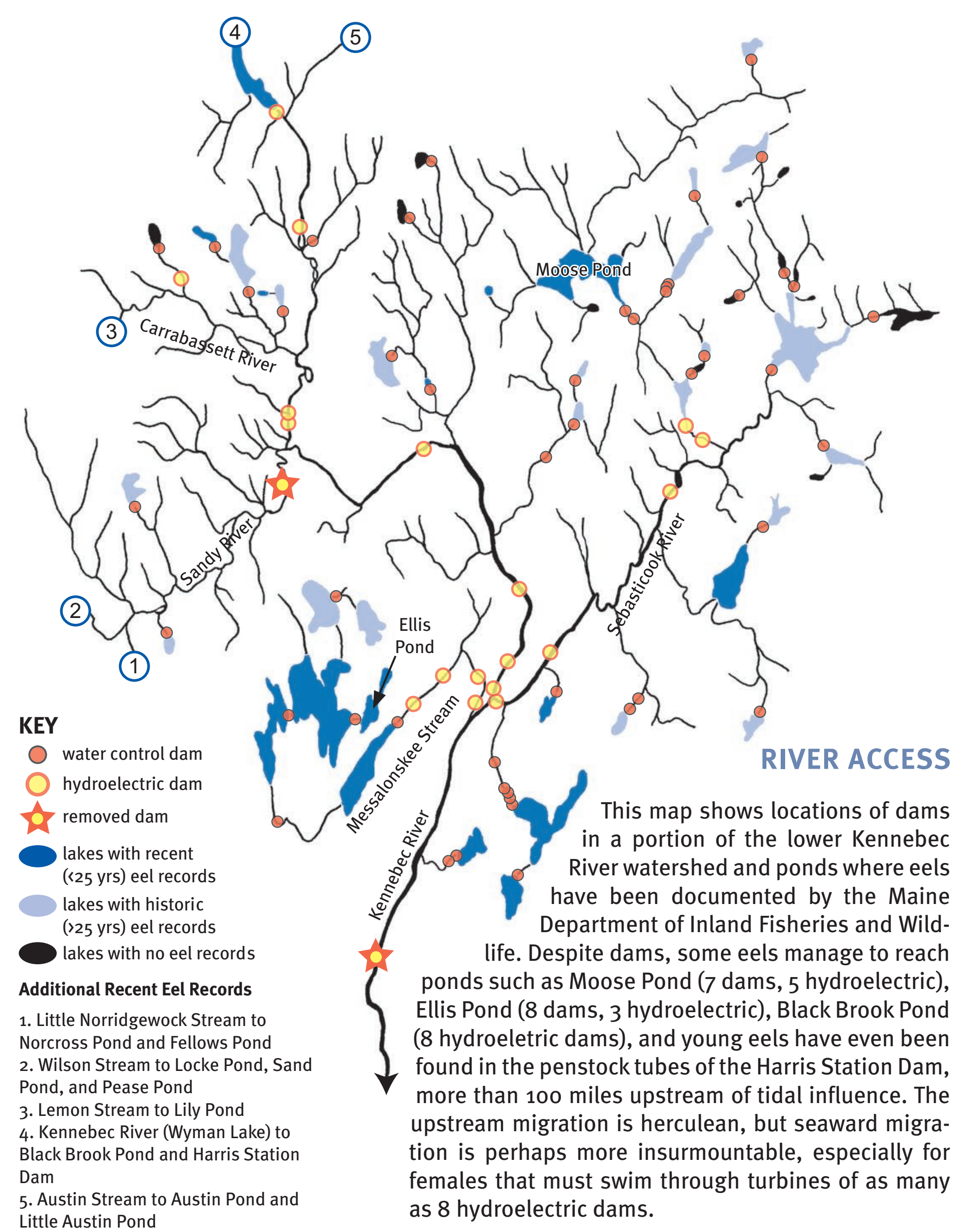
Humans have greatly restricted freshwater access for migratory fish by building dams. In the Gulf of Maine region, people began building dams in the early 1600s and continued in earnest for the next 350 years. Upwards of 10,000 dams may exist in the Gulf of Maine watershed (GOMC 2004). Most dams were not equipped to pass fish, and thus migratory fish populations rapidly declined. Fish ladders and fishways were designed for Atlantic salmon, sometimes for shad or alewife, but most are not suitable for passing eels.

On the downstream journey, eels may have to pass through turbines at hydroelectric dams. Mortality may be 50% or more for some types of turbines, with 80-100% being injured (Haro *et al.* 2003). Eels often must pass by several hydroelectric dams before reaching the sea, and the cumulative mortality for all dams may be very high (McCleave 2001). Larger eels have a much greater chance of being injured by turbines, and unfortunately, these are usually females. The lengthy journey to the Sargasso Sea is hard enough for a healthy eel, and severe wounds at the start of the journey make success much more unlikely.

The viability of the North American eel population may be somewhat independent of migration success in individual rivers. Dams may block upstream migration of juvenile eels into freshwater habitats or even make seaward (spawning) migrations treacherous, but since eels return to the ocean to spawn as a single breeding population, the overall effect of restricted riverine access on breeding success is extremely difficult to assess. This is because a single river may make a tiny contribution to the spawning stock. In contrast, dams impede or block anadromous species from reaching spawning habitat and therefore the dam's effect is immediate and measurable. For example, if Atlantic salmon are blocked from migrating upriver to spawn, that river's stock may soon dwindle to nothing. If eels are unable to migrate upriver (or downriver) in a particular river, juvenile eels may still return to the same river in subsequent years, as abundant as ever, as long as other rivers contribute enough adults to the single breeding population.

ECOSYSTEM QUALITY

Habitat quality and water quality in coastal waters, estuaries, and freshwater habitats have been greatly modified. Rivers around the Gulf of Maine have a long history of watershed



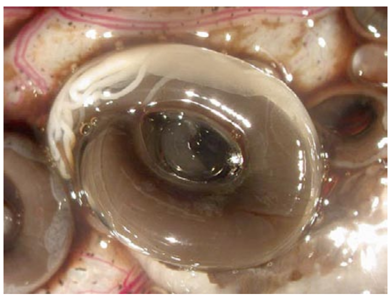
RIVER ACCESS

This map shows locations of dams in a portion of the lower Kennebec River watershed and ponds where eels have been documented by the Maine Department of Inland Fisheries and Wildlife. Despite dams, some eels manage to reach ponds such as Moose Pond (7 dams, 5 hydroelectric), Ellis Pond (8 dams, 3 hydroelectric), Black Brook Pond (8 hydroeletric dams), and young eels have even been found in the penstock tubes of the Harris Station Dam, more than 100 miles upstream of tidal influence. The upstream migration is herculean, but seaward migration is perhaps more insurmountable, especially for females that must swim through turbines of as many as 8 hydroelectric dams.

changes, hydrologic changes, and channel modification caused by log driving and other uses. Many rivers no longer support high native fish diversity and biomass. In addition to habitat-related stressors, eels are susceptible to chemical contaminants and can bioaccumulate toxins, often at concentrations expected to cause health problems in eels or in animals (including humans) that eat them (Hodson *et al.* 1994, Couillard *et al.* 1997). Chronic exposure might affect mortality, growth rates, fecundity, offspring survival, and vulnerability to disease and parasites. Toxins stored in fatty tissue are released during the spawning migration and could affect behavior, orientation, swimming ability, and mating success (Robinet and Feunteun 2002).

NON-NATIVE SPECIES

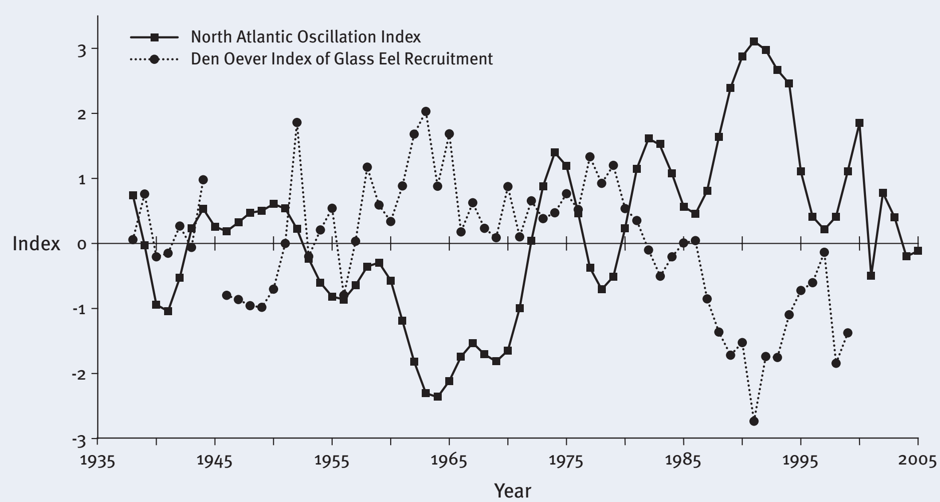
Many nonnative fish and invertebrates have been introduced into coastal waters, estuaries, and freshwater habitats in the Gulf of Maine region. Nonnative fish—such as northern pike, largemouth bass, and smallmouth bass—may eat eels. However, the most important non-native species may be a swim bladder nematode, *Anguillicola crassus*, which is an eel parasite. Native to southeast Asia, the nematode was released in a Texas aquaculture facility before 1995, and it quickly spread to the Chesapeake Bay and Hudson River by 1999 (Barse and Secor 1999), Massachusetts by 2003, and by 2006 was found in Sedgeunkedunk Stream in the Penobscot River watershed in central Maine (Aieta and Oliveira, unpublished data). Prevalence of infection in yellow eels in southern New England watersheds is reported as high as 76%; all size classes of fish are infected though the intensity is highest on large eels. It causes a variety of health problems in eels, and it is thought to adversely affect migrating silver eels. Another parasite, *Pseudodactylus anguillae* (a fluke [Trematode]), has been found in a few Maine populations and may cause summertime mortality in concert with high temperatures and low oxygen (Merry Gallagher, Maine Department of Inland Fisheries and Wildlife, personal communication).



The parasite *Anguillicola*

CLIMATE CHANGE

Climate change is expected to affect American eels through changes in oceanic conditions (currents and vertical mixing) and sea-surface temperatures. Glass eel recruitment indices for the European eel (*Anguilla anguilla*) are strongly correlated with the North Atlantic Oscillation Index (NAOI), sea surface temperature anomalies, and position of the Gulf Stream (Knights 2003). The NAOI indicates variations in the strength of low surface pressure near Iceland and high surface pressure often located over the Azores, particularly during the Northern Hemisphere winter. As the pressure gradient steepens between the Icelandic low and the Azores high (a positive NAOI), the strength of the westerly winds increases and affects ocean currents and precipitation patterns around the North Atlantic. Glass eel recruitment depends on favorable speed and direction of currents (for transport) and suitable conditions for egg hatching and larval survival (temperature, food abundance). Variation in oceanic conditions may help explain variation in recruitment to coastal rivers. Long-term trends in oceanic conditions, either natural or human-influenced (i.e., climate change), could profoundly affect American eels.



Graph reproduced with permission from B. Knights, "A review of the possible impacts of long-term oceanic and climate changes and fishing mortality on recruitment of anguillid eels of the Northern Hemisphere", *The Science of the Total Environment* 310 (2003): 237-244. Recent NAOI values were added to this graph; data from www.cgd.ucar.edu/cas/jhurrell/indices.html.

CHANGES IN OCEANIC CONDITIONS

Oceanic conditions—notably the North Atlantic Oscillation (NAO) and sea surface temperatures—are thought to influence eel recruitment (Knights 2003). The graph above shows the relationship between the NAO Index (NAOI) and the Den Oever Index (DOI), a glass eel recruitment index that has been measured since 1938. The DOI is inversely correlated with the NAOI, and recent declines in American and European eels *(Anguilla anguilla)* is likely due in part to the strong positive NAOI during the last 2-3 decades. During positive NAOI, transport rates to continents may be reduced, migration time may be prolonged, and leptocephali may suffer from low nutrition and increased predation.

THE EEL FISHERY

Humans exploit glass eels, elvers, yellow eels, and silver eels. Glass eels and elvers are harvested for food and overseas aquaculture. The latter created a lucrative market in the 1990s, with prices of nearly US$800/kg ($300/lb) of elvers. The elver fishery began to decline in 1998 because of protective legislation and low market prices. Harvest restrictions led to a 79% reduction in fishing effort for elvers in Maine.

Despite the intensity of the elver fishery during its heyday, it probably had little effect on recent elver recruitment because of the lag time between when elvers migrate up rivers and when they finally spawn. Elvers harvested in the mid-1990s would probably not have returned to spawn until at least 2005 and perhaps not until 2020; scientists may one day show that intense elver harvest affects subsequent breeding and recruitment, but there are no data to support this yet. Robitaille *et al.* (2003) provided evidence that harvest of silver eels in the Great Lakes may have contributed to fewer spawners and lower subsequent recruitment.

Yellow and silver eels are harvested commercially for human consumption and bait, and by anglers for recreation. Commercial harvest methods include baited traps (such as eel pots) and weirs that intercept migrating eels in rivers and estuaries. Weirs can be very effective at trapping eels, especially weirs that span an entire river and may catch almost 100% of migrating eels. In the U.S., only Maine and New York allow commercial harvest of silver eels, whereas every state allows harvest of yellow eels using eel pots. Eel gigs are also used to harvest adult eels through the ice during winter in tidal rivers. Recreational anglers catch yellow and silver eels by hook and line. Anglers also use eels as bait for other species such as striped bass. Harvest pressure can be intense in some rivers, with most adult eels being caught or killed.

Commercial eel weir on the Seboeis River in Maine. Alex Haro

The status of the American eel fishery is poorly understood for several reasons:

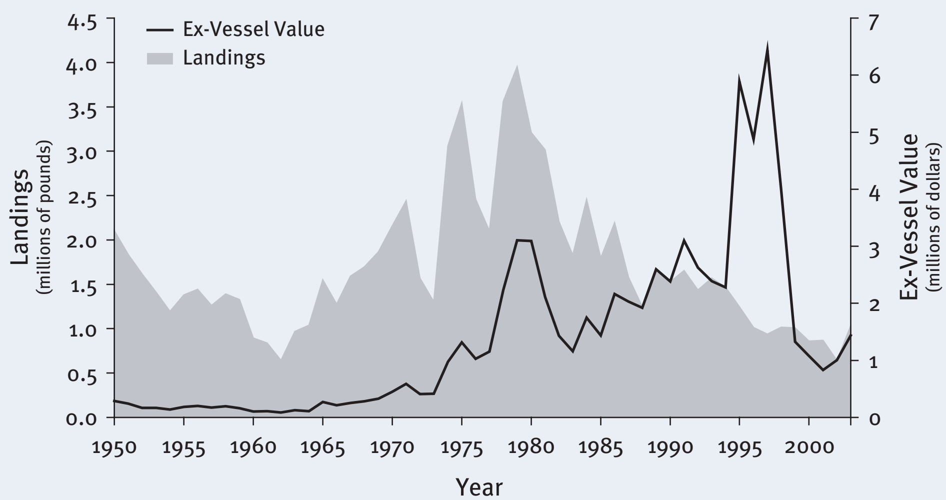
- Inaccurate reporting of harvest and effort
- Stock assessment efforts are limited and non-uniform
- Data collection protocols are inconsistent and not comparable over time or space (geographic range)
- Reliable abundance indices are scarce
- Long-term datasets are scarce
- Harvest data may not reflect population trends because it is influenced by market conditions and fishing effort

The ASMFC is actively addressing these research needs by requiring all member states to implement management plans and develop consistent monitoring and reporting programs.

DECLINING HARVEST

This graph shows annual commercial harvest of American eels (coastal) and ex-vessel value from 1950 to 2003. Ex-vessel value is the value of the harvest as determined by what harvesters are paid. Landings have declined dramatically since a peak in 1980. The ex-vessel value peaked in the mid to late 1990s despite low harvest levels because the intense market demand for elvers. Ex-vessel value plummeted in the late 1990s because of low market prices and greater restrictions on harvest.

Source: National Marine Fisheries Service, Fisheries Statistics and Economics Division. Estimated ex-vessel value is reported in nominal terms and was not corrected for inflation.



PROTECTING AND RESTORING EELS

There are several ways to protect and restore American eels, ranging from broad efforts to improve ecosystem health to focused projects that improve eel passage past dams. This section focuses on improving access to historic habitat and safe passage past dams. With more than sixty rivers, hundreds of small streams, and upwards of 10,000 dams in the Gulf of Maine watershed, it is difficult to decide where to focus restoration efforts. Every river is important, but if resources to protect or restore eels are limited, it may be best to identify rivers that make a larger contribution to the spawning stock, or for which restoration can be clearly demonstrated. Decisions could be based on four guidelines:

1. Focus on hydropower dams that are being relicensed, especially those near the coast

   Hydropower dams are relicensed for 30-50 years, so in our lifetimes, we may get one chance to allow eels to get past a particular dam. The relicensing process is the best time to consider eel passage because of the intense scrutiny given to the costs and benefits of dam operations. Sometimes eel passage should be provided even when there are no such passageways further downstream or upstream—it just depends on which dams are undergoing relicensing first.

2. Focus on dams that restrict access to the largest amounts of high-quality habitat

   High-quality habitat for eels may include rivers, ponds, and lakes with relatively undisturbed habitat, good water quality, few environmental threats, and a good prey base. Low-gradient rivers that connect a series of lakes and wetlands are often very productive habitats, whereas small, high-gradient streams with small watersheds are usually less productive.

3. Assess all migration barriers in a watershed and focus on dams that have few or no barriers upstream

   It makes sense to focus on the first impassable barrier that juvenile eels encounter after entering rivers, but the distance to the next barrier—and habitat quality in between—is also important. Some rivers have many dams and may require a comprehensive plan to address eel passage at all dams.

4. Evaluate eel passage at each dam

   It may seem counterproductive to install elver ladders to get eels upstream, if there is not a safe way for them to get back downstream. However, after eels pass a dam they may spend 10-30+ years in the watershed, giving people considerable time to install downstream passage facilities (or remove the dam). Allowing upstream passage now can essentially "bank" eels in the watershed with the hope that safe downstream passage will be provided by the time these fish mature and return to the sea.

GETTING EELS UPSTREAM

The first step is to research the environmental conditions at a particular location and attributes of eels (i.e., size and behavior) to determine what type of fish passage structure will work best. In the lower part of a watershed, elver ladders designed to pass 60-130 millimeter (2.3-5.1 inches) eels with poor swimming ability are most appropriate. Further upstream, fishways must pass eels that are more than 300 millimeters (11.8 inches) long and strong swimmers. Different climbing substrates can be used to pass eels of different sizes.

Elvers that are 70-100 millimeters (2.75-3.9 inches) long can swim at burst speeds of 0.6-0.9 meters per second (approximately 2-3 feet per second) over distances of less than 1.5 meters (4.9 feet). At water velocities of 0.3 meters per second

THESE TRAITS OF AMERICAN EELS...

- Catadromous (live in freshwater, breed in the ocean)
- Single random breeding population
- Species has enormous geographic range
- Individuals must migrate vast distances
- High age at maturity
- Die after spawning
- Adults feed high on food chain
- Valuable baitfish and food for humans

...CREATE THESE MANAGEMENT CHALLENGES

- Eels have diverse habitat needs and cross many political boundaries and management jurisdictions
- Critical phases in their life cycle are virtually unknown and subject to environmental variables beyond the scope of any management agency (e.g., temperature, currents, climatic variables, and weather)
- Mortality in each phase of their life is difficult to quantify
- Eels accumulate chemical contaminants in their tissue during the long residency in freshwater and coastal areas, causing mortality, behavioral changes, or reproductive effects
- Management and restoration must consider commercial interests, even though fisheries data is often sparse, poorly collected, and not comparable over time or between regions
- It may not be possible to measure the effect of management or restoration in specific rivers, watersheds, or entire regions (such as the Gulf of Maine) on breeding success
- The number of silver eels leaving a river may have no bearing on the number of elvers that return to the same river, unless the river makes a vastly disproportionate contribution to the spawning stock

(1.0 feet/second), elvers generally cannot swim further than 3 meters (9.8 feet) (McCleave 1980). Older juveniles can swim 1.5 meters per second (4.9 feet per second) but cannot swim far against fast water. Water velocities in excess of their swimming speed, or for distances longer than they are able to endure (e.g., long culverts) will hinder migration, particularly if there are not refuges from the current. Strong turbulence and complex flows will also reduce swimming performance.

Rough substrates will slow currents near the bottom and create flow refuges, enabling eels to migrate upstream in otherwise impassable water velocities. Eels are good climbers and can ascend vertical surfaces if there is a wet, rough substrate for them to climb. Nevertheless, a large proportion of eels will not attempt to climb and passage structures should be provided. Eel passes require three basic elements:

- a way to attract eels to the entrance of the fishway,
- suitable placement of the entrance and exit in relation to currents, and
- suitable water velocities in the fishway and rough substrate that aids ascent.

Traditional Fishways, Locks, and Lifts: Most traditional fishways such as fish ladders were designed for migratory fish with excellent jumping or swimming ability. Eels cannot always utilize fishways that were designed for other species; water velocity, jump barriers, and length of the fishway are the greatest hurdles for eels. Locks and lifts are sometimes used, but the techniques to attract fish and move fish within locks and lifts may not be effective for eels. The use of such fishways by eels is rarely monitored because visual counts or collection methods target other species (e.g., salmon, shad, alewife). Therefore, the performance of these fishways for eels is poorly understood, and modifications to existing structures to accommodate eels are still being developed and tested.

Elver ladder on a small river in western Massachusetts. The hose provides an attractant flow, eels crawl up the ramp into a holding tank, and the tank is emptied on the upstream side of the dam. Ethan Nedeau

Eels have the ability to ascend damp vertical surfaces (left), but passage is far more successful if we provide ramps with climbing substrate, like this one on Mallemort Dam in France (right). Alex Haro

Eel Ramp Passes: A common fishway for elvers is a ramp furnished with a climbing medium. The ramp can be installed on the face of, or adjacent to, a dam and has a separate entrance and exit. The climbing medium—such as artificial mesh or bottlebrushes—give eels something to crawl through or over. Construction can be fairly easy and inexpensive, depending on the height of the barrier, size of the river, and environmental conditions. Some eel fishways trap eels in a holding tank, such as a 5-gallon bucket, that biologists can carry above the dam and release. Few elver fishways have been installed on Gulf of Maine rivers, but this could be an effective restoration tool that also gets citizens involved in restoration projects.

Bypass Channels: Bypass channels are constructed around dams to create a riffle and pool environment with more natural substrates and riparian conditions. Eels can easily ascend most bypass channels, provided eels can find the entrance. Water velocity through bypass channels can be manipulated to enhance conditions for migrating eels.

Rock Ramps: Rock ramps are built to replace traditional dams but are constructed out of cobble and boulders. They retain water levels in the impoundment but also provide a more natural flow of water for migratory fish. Rock ramps that include natural vegetation or an artificial climbing medium will provide better passage for migrating eels.

Rock ramp at the outlet of Sennebec Pond in Union, Maine, which replaced a dam but still maintains pond levels. Eric Hutchins

Culverts: Culverts can impede eels because they concentrate flow and create high water velocities that may exceed the swimming speed of eels. Long undersized culverts with smooth surfaces tend to pose greatest challenges for migrating fish. Some culverts are elevated at one or both ends, and drops of only a few centimeters may be enough to block eels. Problem culverts should be replaced by adequately sized culverts with natural bottom habitat and hydraulic conditions that do not restrict fish movement (Massachusetts Riverways Program 2005).

GETTING EELS DOWNSTREAM

Providing safe downstream passage for adult eels is an entirely different challenge than getting eels upstream. Dams and other barriers do not necessarily hinder downstream migration, especially low-head dams and other small structures where water flows over the dam or passes through open gates. The main problem is hydroelectric dams where much of the flow passes through turbines. There are several options for getting adult eels safely past hydroelectric dams, though the scientific basis is still being developed and the technological aspects remain a challenge (Boubee et al. 2003, Richkus and Dixon 2003).

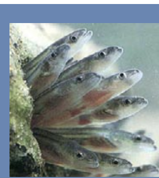
Bypass structures: Bypass structures can allow a safe route for eels, but unfortunately, it is challenging to direct eels toward them (Richkus and Dixon 2003, Amaral et al. 2003). Angled screens can deflect eels toward a bypass, but eels may get pinned against the screens if the water velocity is too high. River debris will usually accumulate on the screens and require constant cleaning by the hydropower company. Because eels avoid lights, lights may be used to direct eels toward a bypass, as long as eels do not habituate to lights over time and turbidity does not reduce the effectiveness of lights. A strong flow of water into the bypass will attract eels, but will result in less water flowing through turbines and less generating capacity.

Timing of Hydropower Operations: The most effective way of getting eels past a hydroelectric dam is to turn off the turbines during peak migration and increase spill over a dam. Most eels migrate on dark rainy nights from September to December, and some hydropower companies have license articles that require them to turn off turbines at night during those times. Scientists are working on models that better predict eel migration so that companies may adjust their hydropower production to accommodate eels (Durif *et al.* 2003, Haro *et al.* 2003). A drawback is that hydropower companies may generate less power by closing their turbines.

Dam removal: Removing dams is the most effective way to get eels downstream or upstream. Dam removal reconnects fragmented river systems, restores habitat for migratory and resident fish, restores natural flow regimes, and may improve water quality. During the riverbed restoration phase of dam removal, low velocity areas need to be graded into the riverbed to allow weak swimmers, such as juvenile eels, to get upstream. Ironically, dams may create productive and stable environments that eels may thrive in, provided the eels can access these waters. Natural lakes and artificial impoundments alike provide refuge for eels at times when rivers conditions are stressful, such as low-flow periods or during the winter.

Removal of the Madison Electric Works Dam on the Sandy River in Norridgewock, Maine. The dam was removed in the summer of 2006, allowing diadromous fish access to the watershed of Maine's 12th largest river. Eric Hutchins

OUTLOOK FOR EELS



The American eel population is declining—fewer elvers arrive in our coastal estuaries and rivers, and scientists fear that fewer silver eels return to the Sargasso Sea each year to spawn. It is difficult to pinpoint or address the possible causes of the decline. For example, climate change may exert a strong influence on juvenile eel migration and survival, but the social and political will to address this global issue is lagging. At best, efforts to curb climate change (such as emission standards) will take decades to have a meaningful effect.

Although global-scale problems are difficult to address in regional conservation strategies, people in the Gulf of Maine region can have immediate and profound effects on the freshwater phase of American eels by restoring historic habitat and reducing controllable sources of mortality. We are poised to lead by example: momentum for river restoration and aquatic conservation has been mounting in recent decades. Dams and other unnatural obstructions are being removed or modified to restore native species. Knowledge of eel biology and behavior is being used to develop practical eel passage technology for barriers that cannot be removed. Pollution controls have led to many waterbodies being cleaner now than they have been in the last century; these efforts have given native fish a chance to thrive in waters that are once again "fishable and swimmable" (one of the central goals of the Clean Water Act).

Unfortunately, we may have no way of knowing for sure how much difference individual efforts to protect and restore rivers will make to the American eel population. We need faith that by restoring ancestral migration routes, and by limiting the number of eels that die by our hands, we are enabling a species to persist as it has for millions of years. Restoring eels is like contributing to a public radio station—supporters make the phone call during the fund drive and feel good that their donation improves the quality of life for themselves and others. Each contribution may seem like a tiny fraction of the station's operating costs, and sometimes their perceived inability to "do more" causes people to do nothing at all. Yet for public radio, each contribution does help, and the show of support is in many ways just as important as how much individuals actually contribute. In the same way, *every* restored river is important because it contributes to the health of the eel population and allows countless other native species—such as Atlantic salmon and bald eagles—to regain their place in our waters, lands, and skies. Our collective effort represents a culture of environmental concern and action. American eels will test our resolve to reconnect fragmented ecosystems for the benefit of all species, and to act locally while thinking globally to protect our natural resources.

PARTNERS IN RESTORATION

In 2001, the Gulf of Maine Council on the Marine Environment (GOMC) and the National Oceanic and Atmospheric Administration (NOAA) formed the Habitat Restoration Partnership to promote and fund restoration projects. One of its goals is to create a common understanding of the social, economic, and environmental benefits of habitat restoration. This fact sheet is intended to help accomplish this goal and to promote the Council's Riverine Habitat Policy Objective **"...to support restoration and enhancement of riverine habitats and improve access for fish and wildlife. Emphasis will be placed on restoration of migratory fish, whose historic habitat has been greatly diminished."**

Signs to educate the public about eel passage past dams indicate a growing public appreciation of the plight of American eels. Ethan Nedeau

A horde of elvers swimming upstream on a Massachusetts river. Tim Watts

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WEB SITES

Atlantic States Marine Fisheries Commission: American Eels
www.asmfc.org/americaneel.htm

Gulf of Maine Council on the Marine Environment
www.gulfofmaine.org

NOAA Restoration Center
www.nmfs.noaa.gov/habitat/restoration

U.S. Fish and Wildlife Service: The American Eel
www.fws.gov/northeast/ameel

Gulf of Maine Council on the Marine Environment

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