ATTACHMENT D

AMERICAN EEL ANALYSIS

AMERICAN EEL PRESENCE AND MOVEMENT UPSTREAM AND DOWNSTREAM OF LAKE LIVINGSTON DAM

Background, Life History, and Regulatory Status

The FWS Clear Lake office requested from the Cooperative an aquatic study to evaluate the Lake Livingston Dam as a possible barrier to upstream movement of eels, ways to move eels upstream past the dam, methods to prevent adult eels from entering turbines, and the current distribution of eels around Lake Livingston Dam.

The eel is a facultative catadromous species that lives most of its life in estuarine or freshwater and when sexually mature, migrates to the Sargasso Sea in the southwest Atlantic Ocean to spawn and die. Juvenile eels are carried by oceanic currents and, as they mature, enter freshwater streams located from the north shore of Venezuela along the Gulf of Mexico coast up to Canada. The eels can migrate upstream for hundreds of miles and live for up to 57 years (Solomon and Beach, 2004a, 2004b) before becoming sexually mature and beginning their return to the Atlantic Ocean. Previously, it was thought that eels only grew in freshwater, while recent evidence shows eels in estuaries grow faster, mature earlier, and migrate downstream as silver eels earlier than eels in freshwater (FWS, 2007). These recent studies also show some eels may mature without ever entering freshwater. Several reports describe eel life history in detail (ASMFC, 2000; EPRI, 1999) with the vast majority of research on the life history, migration patterns, etc. of eels being focused on the east coast of the U.S. There is only limited information on the eel in the Gulf of Mexico watershed.

Commercial fishery data and monitoring of eels using fish passes along the east coast of the U.S. and Canada suggest the population of eel may be declining. Potential causes for the possible decline in population size include increased commercial harvest in response to increasing demand from Asia, commercial harvest practices that tend to remove the reproductive females in the population, water pollution, changes in oceanic currents, and losses to parasitism, particularly by the exotic parasitic nematode, *Anguillacola crassa*. Two other possible contributors to reduced population size include reduced access to habitat resulting from the construction of dams and mortality of eels that attempt to migrate downstream through hydropower facilities. As a result of the possible decline in the eel population, federal and state agencies have increased the study and monitoring of eel populations along the east coast and advocated increased protection of eel. Suggested protective measures include modifications in commercial harvest season, sizes ranges, bag limits, construction of passes to allow upstream migration through dams, and protection of sexually mature eels migrating downstream through hydropower facilities. Although commercial fishery data and monitoring of eels moving upstream through fish passes suggest a possible decline in the population size, other studies show juvenile glass eel recruitment levels have not changed recently (FWS, 2007).

In concluding that the American eel is not likely to become an endangered species, FWS (FWS, 2007), found:

> "…the American eel remains widely distributed over their vast range including most of their historic freshwater habitat, eels are not solely dependent on freshwater habitat to complete their lifecycle utilizing marine and estuarine habitats as well, they remain in the millions, that recruitment trends appear variable, but stable, and that threats acting individually or in combination do not threaten the species at a population level."

Upstream Eel Passage

Solomon and Beach (2004a, 2004b) provide an extensive review of eel biology and life history related to migratory behavior, fundamental approaches to providing upstream passage facilities, and basic design guidelines for eel passage facilities. Although their work was conducted primarily in England, scientists consider the life history and behavior of the European eel (*Anguilla anguilla*) and the American eel to be practically the same. Therefore, Solomon and Beach (2004a, 2004b) review eel passage facilities in the U.S. and Canada as well as in England and Europe.

When considering provision of eel passage upstream of dams, it is necessary to understand eel behavior related to upstream migration. This information is summarized below (Solomon and Beach, 2004a, 2004b). It is important to understand that there is considerable variability in data from different locations and there is practically no information about these patterns in the Gulf of Mexico.

- Elvers enter estuaries in fall and winter (England and Ireland) and begin migrating upstream into the rivers in the spring.
- Elvers begin their migration into rivers in the spring and this upstream migration may continue through their lives. Swimming activity increases as temperature rises and migration may increase when temperatures rise above 20°C.
- Eels that migrate into flowing waters tend to gather close to the main flow at the most upstream point below obstructions. However, high flows may impede the migration of smaller individuals.
- Elvers may migrate during the day or night; however, eels that survive their first year typically migrate at night.

- Elvers and small eels up to 100 mm in length can climb near vertical, wetted, surfaces if the surfaces are adequately rough. Eels of all sizes may move over wet ground near the stream.
- Young eels tend to migrate more because of higher eel density. If the density of eels is relatively high, young eels will continue to disperse in search of an acceptable density of eels, while older eels may move upstream more due to random dispersion.
- Male eels mature earlier than female eels.
- Once in freshwater, elvers and young eels tend to migrate as individuals, not in schools, and move along the bottom rather than by swimming in the open water.
- Young eels may migrate in respond to “odors” or chemical clues in the water that are released by upstream eels.
- Young eels and elvers may be susceptible to predation, particularly in areas where they are concentrated.

Solomon and Beach (2004a, 2004b) also identify six basic approaches to providing upstream eel passage. These fundamental approaches account for the eel’s inability to jump, to climb a vertical barrier greater than 50 percent its length, and its relatively poor swimming ability.

- Incorporate a channel that allows eel to ascend under controlled conditions within their capabilities. This is the most widespread of the six approaches and commonly involves the use of ramps with a substrate that helps the eel wiggle up the ramp.
- Trap the fish at the base of, or part the way up the face of, the obstruction and release them upstream.
- Allow the fish to swim through the barrier (e.g. through an orifice or pipe), which would normally require some mechanism for reducing water velocity through the aperture.
- Lift the fish either in a fish lock or a fish lift.
- Create conditions at the barrier to allow ascent, for example by roughening the back of a small weir or providing rocks to generate edge effects, which is used in concert with the first recommendation.
- Removal of barriers.

Downstream Eel Migration

As with upstream migration, Solomon and Beach (2004a, 2004b) identify eel behavior associated with downstream migration. It is important to remember there is considerable variability in data from different locations and practically no information about these patterns in the Gulf of Mexico watershed.

- Downstream migration begins in the summer to fall, perhaps earlier in the year for eels further from the ocean.
- Eels begin to migrate downstream as they become sexually mature and as certain environmental cues stimulate migration.
- Eels from further upstream have a higher probability of being females, referred to as "silver eels" while eels nearer the estuary have a higher probability of being males, "yellow eels."
- Males tend to mature at an earlier age than females. In English river systems, males ranged from 29 to 46 cm in length and 3 to 33 years in age while females ranged from 35 to 102 cm in length and 5 to 57 years in age.
- Migration generally occurs in the dark (at night, during new moons or periods of elevated turbidity) and at elevated flows or during rainfall events.
- Although the period of migration may last for months, most of the migrating eels in a water body migrate during a few days of the migratory period.
- Yellow eels tend to swim downstream close to the substrate while silver eels tend to swim downstream in open water.

Deterring Eels from Hydropower Turbines

A proportion of eels migrating downstream through hydropower turbines are injured or killed depending upon the types of turbine, size of eels, relative velocities, flow, and where the eel enters the turbine (***Table 1***). Mortality or serious injury results from the physical trauma of the eel contacting some part of the turbine during transit through the hydroelectric facility.

Considerable research evaluated different technologies and techniques for minimizing eel mortality and injury resulting from passage through hydropower turbines (Richkus and Dixon, 2003). Some of these techniques provided highly variable results and others were tested only in laboratory or experimental conditions.

Table 1. Comparison of Mortality Estimates for American Eels Migrating Downstream Through Hydropower Turbines

PERCENT SURVIVAL	STUDY	NOTES
76 (for propeller type) 84 (for Francis unit)	Desrochers (1994) as reported in EPRI (1999)	Mortality testing with 881 to 889 mm eels at the Beauharnois Complex, St. Lawrence River
73	NYPA (1998) as reported in EPRI (1999)	Mortality after 88 hours of 900 mm eels passed through a propeller-type turbine at the St. Lawrence-FDR Project
63	NIMO (1996) as reported in EPRI (1999)	Mortality after 48 hours for 500 to 750 mm eels through a vertical propeller turbine at Raymondville on the Lower Raquette River, New York
94	NIMO (1995) as reported in EPRI (1999)	Mortality after 48 hours for 500 to 750 mm eels through a vertical Francis unit at Minetto on the Oswego River, New York
91	RMC (1995) as reported in EPRI (1999)	Mortality for 560 to 1118 mm eels passed through a vertical Francis turbine at the Luray Project on the Shenandoah River, Virginia
50 to 80	Berg (1986) as reported in EPRI (1999)	Mortality of eels passed through Kaplan turbines with vertical shafts
60	Casselman (2005)	Estimated turbine mortality of eels passing the St. Lawrence
0 to 60 (Kaplan turbines) 0 to 91 (Francis turbines)	Monten (1985) as reported in Solomon and Beach (2004a, 2004b)	Mortality of adult eels at hydroelectric power facilities in Sweden.

- Light – Experiments with lights as a deterrent were conducted from the 1940s through the 1990s, sometimes in laboratory settings and sometimes in the field. Recent results are inconsistent.
- Sound – One study showed eels passing an experimental source of infrasound may have been diverted to the opposite shore of the river where there was no source of infrasound.
- Water jets and air bubbles – These techniques have not been effective in deterring migrating silver eels. It appears the eels may temporarily avoid the barriers, but eventually acclimate and eventually pass through the deterrents.
- Electrical fields – Eels are very sensitive to electrical fields, but it has been very difficult to use a voltage which will deter the eels without stunning them. Additionally, the cost of installing large electrical screens is expensive and requires extensive maintenance due to electrolysis.
- Angled bar racks and louvers– Some eels may be diverted under certain water velocities using certain angles of bar racks or louvers. The effectiveness of diversion may be reduced by the tendency of eels to attempt passing through the structures.
- Screens – Eels can be diverted without injury by Wedge-wire screens with flows in excess of 0.7 m/s. One study suggested a screen angle of 40° to effectively guide eels.
- By-pass flows – Studies have shown that eels will by-pass turbines if the velocities at the by-pass are similar to velocities at the turbine intake bar racks; however, the studies have also suggested a wide range (between 5 and 50 percent) of total river discharge may need to go through the by-pass.
- Trap and transport – If downstream migrating eels can be trapped, they can then be transported downstream of the turbines and released.
- Altered generation schedule – If it is possible to identify the period of migration downstream, generation can be ceased during the night hours during the migration period. Hoar (personal communication with A. Hoar, FWS, September 2008) suggested this method is the most reliable for protecting eels migrating downstream.

Discussions with Alex Hoar, FWS, (personal communication with A. Hoar, FWS, September 2008) and with Kevin McGrath, New York Power Authority, (personal communication with K. McGrath, New York Power Authority, September 2008) indicate there have not been significant, recent advances in methods to deter silver eels from hydropower turbines. Hoar suggested there have been relatively few operational applications at hydropower facilities with a long enough period of use to adequately judge long-term effectiveness. His opinion was that the most successful technique at this time appears to be an altered generation schedule, which is used at some hydropower facilities. This involves ceasing generation at night during the estimated period of downstream migration. He acknowledged there are some water bodies where eels migrate downstream during the spring in addition to the fall, making cessation of generation less cost effective. Although light arrays have deterred eel movements in some situations, the use of light is potentially problematic because it can attract other fish. Mr. Hoar's opinion was that angled bar racks may be the second most effective approach for reducing eel mortality compared to altered generation schedules.

McGrath (personal communication with K. McGrath, New York Power Authority, September 2008) suggested light may be an effective deterrent. However, recent information suggests as many as 15–20 percent of eels may migrate during the day and light would not effectively deter those eels. He mentioned research in Europe where eels are maintained in a tank. It is believed that when eels in the tank increase their movement, eels in the watershed may also be increasing their movement, hence increased probability of engaging in downstream migrating behavior. This information may be used to guide the optimal time to cease power generation.

American Eels in the Trinity River Watershed

Eels have been encountered in the Trinity River watershed since 1939. The river extends approximately 121 river miles upstream from Trinity Bay to Lake Livingston Dam. The East Fork, West Fork, Elm Fork and Clear Fork of the Trinity River join at different locations to form the mainstem Trinity River in the Dallas-Fort Worth area approximately 260 miles upstream of Lake Livingston. The river and its tributaries extend 715 miles from the coast and the entire basin covers 17,965 square miles (TRA, 2008c). Records of eel collected in the Trinity River watershed are listed in chronological order.

- 1939 – One individual collected from White Rock Lake (Trinity River watershed, Dallas County) (Texas Cooperative Wildlife Collection, 2008).
- 1964 – One individual collected from the Trinity River from a location not otherwise specified (Texas Cooperative Wildlife Collection, 2008).
- 1965 – Parker (1965) describes the eel as rare in the Galveston Bay system and having been collected near the mouth of the Trinity River for a class Project by the Department of Wildlife Management, Texas A&M University. The year of collection was not noted. Parker's report also summarized species collected by the U.S. Bureau of Commercial Fisheries from 1961 to 1964 from the Galveston Bay

system. Eels were not collected during that period of sampling by the U.S. Bureau of Commercial Fisheries.

- 1975 – Two eels were collected during sampling with rotenone from North Lake in Dallas County in 1975 (Texas PWD, 1976).
- 1993 – One eel, 356 mm total length, was collected by Texas PWD using electrofishing in Anahuac on October 12.
- 2000 – Five large eels were collected by the Texas PWD Inland Fisheries biologists while electrofishing for largemouth bass along riprap in Lake Lavon during July.
- 2005 – An angler caught the record eel for Lake Lavon on July 5. This eel was 991 mm total length.
- 2008 – Texas PWD staff collect striped bass brood stock from the Trinity River just downstream of the Lake Livingston Dam stilling basin each year around April using boat-mounted electrofishing. Texas PWD biologists who participate in this collection effort stated that a few eels are seen during each spring's collection effort.

Texas State Department of Health Services fisheries biologists conducted extensive electrofishing in the Clear Fork Trinity River, the West Fork Trinity River, and the mainstem Trinity River in the Dallas-Fort Worth area during 4 weeks in June and July 2008 without encountering any eels.

American Eels in Texas – Published Records

Extensive review of available literature suggests eels are not abundant anywhere in Texas, particularly when compared to eel populations along the Atlantic coast of the U.S. and Canada. Over the period from 1950 to 2007, the National Marine Fisheries Service (NMFS) reported a commercial harvest of 229 pounds of eels from Texas for only 1 year, which was 1984 (NOAA, 2008). The chart given below compares the historical commercial eel harvest for Texas to selected Atlantic coast states. Robitaille et al. (2003) describe eel as the "most abundant, easily caught" commercial fish along the St. Lawrence River estuary during the 1930s. Eels were considered very abundant in the past in streams of the east coast of the U.S., possibly making up 25 percent of the fish biomass in those streams (ASMFC, 2006). Gephard (2005) stated the eel is the most widespread and abundant animal in freshwater habitats in Connecticut. In the same forum, Casselman suggested that at one time, eels were "half the inshore biomass in the Great Lakes."

Comparison of American Eel Commercial Harvest from Four States

State	Years of Commercial Harvest (from 1950 to 2007)	Pounds Harvested from 1950 to 2007	Dollar Value of Harvest from 1950 to 2007
Maine	53	2,576,320	$15,426,836
North Carolina	58	10,106,155	$8,284,812
Texas	1	229	$46
Virginia	58	29,966,463	$17,125,437

Numerous interviews, in addition to an extensive review of literature and databases, have been conducted with fisheries biologists and scientists in Texas with 20 to 30 years experience sampling fish communities in Texas and the Trinity River (personal communications with G. Garrett, Ph.D, Inland Fisheries Division research biologist at the Heart of the Hills Hatchery, Texas PWD, 2008; E. Hegen, Regional Coastal Fisheries director for the lower coast of Texas, Texas PWD, Rockport, Texas, 2008; B. Hysmith, Inland Fisheries Division District supervisor, Region 2, Texas PWD, Pottsboro, Texas, 2008; B. Whitesides, Retired Distinguished Professor Emeritus, Texas State University, 2008; G. Linam, Stream Assessment team leader, Inland Fisheries Division, Texas PWD, 2008). Texas scientists acknowledge eels are present in Texas and may be fairly widespread; however, there is no indication from historical records or current monitoring efforts that eel densities have ever approached the levels recorded from Atlantic coast states.

- The 1894 Bulletin of the U.S. Fish Commission report, "Fishes of Texas and the Rio Grande Drainage," summarized fish collections in Texas back to 1851 when there were the "…first collections of fishes in this region for scientific purposes…" eels were reported collected in:
  - 1859 – mouth of the Rio Grande, Texas,
  - 1875 – 3 specimens from the Rio Grande near Santa Fe, New Mexico, and
  - 1884 – Barton Springs (Colorado River watershed in Austin) (this specimen was an adult, 32 inches long) and San Marcos Springs (Guadalupe/San Antonio River watershed in central Texas).
- Three eels (150 mm, 570 mm and 630 mm long) were collected from a salt water pond adjacent to Aransas Bay (Mission/Aransas rivers watershed) by Kemp (1950). The pond was occasionally connected to the bay by high tides.

- Ginsburg (1951) described examining specimens from the mouth of the Rio Grande, Fort Clark (Las Moras Creek or springs in the Rio Grande watershed), Corpus Christi (Nueces River watershed), Copano Bay (Mission/Aransas rivers watershed), New Braunfels (Guadalupe River watershed), Colorado River at Austin, and Galveston Bay. Some of the specimens he examined may have been collected in the work summarized in the 1894 Bulletin of the U.S. Fish Commission report mentioned earlier.
- Knapp (1953) described the eel as "Not common in Texas, but scattered generally throughout the state." It appears Knapp's conclusions are based upon collections made in the nineteenth century during the boundary surveys conducted by the U.S. Army, collections made by Texas A&M University students from the Red, Guadalupe, Brazos, Pecos and Neches rivers from 1950 to 1952, collections by the Texas Game and Fish Commission on the Guadalupe River around 1950, and collections by Dr. Clark Hubbs and Dr. Richard Baldauf from the Guadalupe, Nueces, and Neches rivers and parts of northeast Texas.
- Treviño (1955) summarized the results of fish collections using seines at 60 sites in the Rio Grande from the river's mouth upstream to Del Rio prior to 1955 by Treviño, C. Hubbs, and L.V. Guerra. One American eel was collected upstream of Laredo in Webb County on February 26, 1954.
- Hubbs (1957) stated that American eels "occupy the large rivers" over most of the eastern and southern portions of the state.
- Riggs and Bonn (1959) summarized 10 years of sampling from 1948 to 1958 in Lake Texoma in Oklahoma and Arkansas. They stated that eels are common in the tailwaters below the Lake Texoma Dam where eels are regularly collected and frequently caught by anglers. They also stated regarding Lake Texoma upstream of the dam that "Five large specimens are known to have been taken by fishermen through 1950 but none since."
- Bryan (1971) sampled the Arroyo Colorado tidal in south Texas with a 10-ft otter trawl and one eel was collected during the sampling from 1966 to 1969.
- One eel was collected in Halls Lake, a tertiary bay on the San Jacinto-Brazos River watershed in the spring of 1971 during monthly sampling at 23 locations with seines and trawls for a year (Moffett, 1975).

American Eels in Texas – Museum and Agency Sources

- Texas CEQ (2008e, 2008f): Surface Water Quality Monitoring database. This database contains primarily water quality data, but also fish data back to 1970.

There is no record of eels in the database. A review of reports of biological collections for other analysis (receiving water assessments, use attainability analysis, etc) did not reveal any studies in which eels were collected.

- Texas Cooperative Wildlife Collection at Texas A&M University, May 2008: The collection holds American eel specimens from eight different collections in Texas from 1939 to 2005. Some of these specimens are referred to in the Texas Natural History Collection May 2008 report.
- Texas Natural History Collection at the University of Texas at Austin, May 2008: The collection identifies eel specimens from 45 different collections in Texas from 1939 to 1980.
- Texas PWD, Coastal Fisheries database, August 2008 (Texas PWD, 2008e): This database contains records from the mid-1970s to near present from over 100,000 individual sample events along the Texas coast. The database contains records for five eels collected in five samples. Two of the eels were collected during a massive freeze fish kill in January 1984. A third eel was collected during a red tide fish kill in September 1986. The eels ranged in length from 121 to 942 mm total length.
- Texas PWD, Fish Kill database, May 2008 (Texas PWD, 2008f): The fish kill database contains records of fish kills across the state back to the 1960s. Many of the fish kill records include lists of species killed. Two fish kills in the database have records which included eels. One dead eel, 23 inches in length, was found April 21, 1996, during a fish kill on Boggy Creek (Lavaca River watershed) near the town of Shiner. A number of American eels ranging in length from 14 to 24 inches were also killed in the Medina River (Guadalupe River watershed), Bexar County, in September 1985 as a result of a sulfuric acid spill.
- Texas PWD, Inland Fisheries database, August 2008 (Texas PWD, 2008g): This database contains records from 1975 to near the present from over 4,000 fish surveys with over 4.6 million fish collected. These surveys focus on sport fish. Since eels are not considered sport fish, it is possible eels were collected, but information about their collection was not stored. This database contains records of 15 fish surveys which collected 21 eels. Nearly all eels were collected using electrofishing techniques and they ranged in length from 356 to 834 mm total length.
- TRA (2007g): Trinity River Fish Database in Microsoft Access, compiled by Dr. George Guillen of the University of Houston at Clear Lake. This comprehensive review of 69 citations describing fish collections from the mainstem Trinity River has one eel record.