State of Maine
120th Legislature
First Regular Session

Eel and Elver Management Fund Plan

A Report to the Joint Standing Committee on Marine Resources

May 2001

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Executive Summary

The Commissioner of the Department of Marine Resources (DMR) is required to present a plan to the Joint Standing Committee on Marine Resources for expenditures from the dedicated Eel and Elver Management Fund by May 1 of each year for the next fiscal year, beginning in calendar year 1997. In order to develop the plan, the Department of Marine Resources formed a 12-member Eel and Elver Management Fund Committee, representing elver, yellow eel, and silver eel fisheries; hydro-electric interests; law enforcement; academia; and resource managers from DMR and the Department of Inland Fisheries and Wildlife (DIFW). The Committee met three times to identify and prioritize research, monitoring and enforcement needs.

This document summarizes the research, management and enforcement undertaken on eels and elvers in 2000, lists proposed work for 2001, and presents a plan for expenditures from the fund for fiscal year 2002. The proposed expenditures will fund research, monitoring, and enforcement needs which were identified by the Committee.

Emergency legislation was passed in 2000 that authorized the Commissioner of DMR to establish a lottery system under which a person who did not hold an elver license in the previous year could become eligible to obtain a license, with the stipulation that the total number of elver licenses issued not exceed 827, and that in 2000, only people with a two-year history in the elver fishery were eligible to participate in the lottery. Over 250 people entered the lottery, but only 56 of the 86 lottery winners purchased a license. A total of 754 fyke nets and 378 dip nets were licensed, but few of the fyke nets were set during the season, probably due to low prices. Dealers reported purchasing 2,625 pounds of elvers at an average price of $10.80/pound.

In 2000, the Department continued a field study at Boothbay Harbor to investigate the efficiency of the elver fishery. Two elver fyke nets were fished below the head-of-tide to mimic the fishery, and a third net was set above the head-of-tide to capture elvers escaping into freshwater growth habitat. The "escapement" net caught 11% of the glass eels. This study probably represent a worst-case scenario, because eels are able to enter the freshwater pond only under certain environmental condtitions.

The Department also continued a study to determine appropriate placement of upstream eel passage at several hydropower projects. At each project, eel passages were installed and tended at least three times week; eels were counted, weighed, and measured. Approximately 81,628 eels were passed at Ft. Halifax and 37,207 at Benton Falls on the Sebasticook River. Approximately 6,462 eels were passed at Hydro-Kennebec on the Kennebec River, and 5,681 were passed at Veazie on the Penobscot River. Passages were installed at Lockwood and Shawmut dams, but were rendered inoperable by high water.

A telemetry study of the behavior of downstream migration of silver eels at dams was conducted on the Sebasticook River at the Benton Falls and Ft. Halifax projects. A total of 12 eels were fitted with radio tags and released on three dates. At Benton Falls, one eel ceased migrating, three passed through an operating turbine and presumably died, one used a surface bypass, and one passed through a nonoperative turbine. All eels that reached Ft. Halifax used the Obermeyer gate or bypass, however, the turbines were not in operation due to low flow conditions. Some eels passed within hours of arriving at a project, while others did not pass for days. Eels were primarily active at night.

A progress report on research being conducted by Merrie Gallagher (UM) and a final report on research conducted by Lia Daniels and Joan trial are also included in this document.

One new monitoring initiative, the young-of-year (YOY) survey requred by ASMFC, is planned for the 2001 sampling season. In addition, DMR personnel will continue to obtain harvest, effort, and location data for all eel fisheries; assess bycatch of the elver fishery; install and monitor upstream passages and obtain recruitment data; study downstream passage measures; and assist DEP in obtaining eels for toxic testing.

Eel and Elver Management Fund Committee

The Department of Marine Resources formed the Eel and Elver Management Fund Committee in 1997 to develop a multi-year plan for expenditures from the fund. The 12 members of the committee represent elver, yellow eel, and silver eel fisheries, hydroelectric interests, law enforcement, academia, and resource managers from DMR and DIFW. The Committee met on three occasions to develop a comprehensive list of research, monitoring, and enforcement needs (Table 1). The Committee meets annually to review activities from the previous fiscal year and to consider those proposed for current fiscal year. The names, affiliations, and addresses of the committee members are shown below. Patricia Bryant, representing the Elver Association, attended the annual meetings beginning in 1999.

Name / phone number	Affiliation	Address
Patricia Bryant 563-5611	Elver Association	74 Duck Puddle Road Nobleboro, ME 04555
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DMR research, monitoring, and enforcement activity in 2001

Elver fishery

Emergency legislation was passed in 1999, which instituted a limited entry system for the elver fishery, reduced the amount of gear a harvester could use, and decreased the length of the season. Participation in the fishery was limited to 827 people, initially those who held elver licenses and gear tags in each of the three years of 1996, 1997, and 1998. Of the 827 eligible harvesters, just 744 purchased licenses, a 68% reduction compared to 1998 (Table 2, Table 3). The amount of gear allowed per individual in 1999 was equal to the average amount of gear used by that individual in 1996, 1997, and 1998 with a maximum of two units. A total of 438 dip nets and 804 fyke nets were licensed in 1999 (Table 3), representing a 79% reduction in gear compared to the previous year. In addition to these changes, the elver fishing season was reduced approximately three weeks; it now begins on March 22 and ends on May 31.

Emergency legislation passed in 2000 authorized the Commissioner of DMR to establish a lottery system under which a person who did not hold an elver license in the previous year could become eligible to obtain a license, with the stipulation that the total number of elver licenses issued not exceed 827, and that in 2000, only people with a two-year history in the elver fishery were eligible to participate in the lottery. A total of 260 people entered the lottery for the 83 available licenses, but just 56 of the 83 lottery winners purchased a license. The amount of gear allowed per lottery winner was equal to the average amount of gear used during the person's two-year history, with a maximum of two units. A total of 378 dip nets and 754 fyke nets were licenses in 2000. Few of the licensed elver fyke nets were set during the 2000 season, presumably because of the low prices paid by dealers. Elver dealers reported purchasing 2,625 pounds of elvers in 2000 at an average price of $10.80/pound (range $10-$13/pound). Approximately 98% of the elvers were captured by fyke net. Preliminary numbers of licenses, fyke nets, and dip nets sold for the 2001 season indicate a further reduction in the fishery (Table 2, Table 3).

Elver escapement studies

Introduction

The elver fishery is relatively recent, and its impact on the recruitment of juvenile eels to inland waters, the primary growth habitat for the species, is unknown. The objective of this two-year study, initiated in March 1999, was to estimate the efficiency of the elver fishery, i.e. to determine what proportion of the elver population escapes the fishery and recruits to freshwater habitat.

Methods

The study was conducted at the outlet of West Harbor Pond, Boothbay Harbor (Fig. 1). At this site, fresh water from Knickerbocker Lakes and West Harbor Pond flows through a culvert under Route 27 directly into high salinity coastal water. A wooden dam at the end of the culvert prevents salt water from entering the pond except during spring flood tides greater than 11 ft. The mean tidal range at this site is 8.8 ft, and mean spring tidal range is 10.1 ft. Approximately 10 years ago, DMR installed a steeppass fishway at the dam, which was designed to pass adult alewives. When tidal height exceeds 11 ft, flow in the fishway reverses, and eels near the fishway entrance are carried "downstream" by the current into West Harbor Pond.

To study the efficiency of the elver fishery, two elver fyke nets were set below the dam (i.e. below the head-of-tide) to represent commercial fishing effort (Fig. 1). Net 1, 16-ft long (codend to wingtip) and 4-ft high, was set approximately 75 ft below the dam. Net 2 , 30-ft long and 7.5-9.5-ft high, was set approximately 25 ft below the dam. Net 3 was set immediately above the dam and fishway in fresh water (Fig. 1) to capture the eels that escaped into growth habitat. The wings of net 3 were stapled to wooden strips, which were fastened to boards bolted to the bridge abutments. If a net had to be cleaned or repaired, it was replaced with a similar sized net.

In compliance with the elver fishing laws, nets 1 and 2 were set on the opening day of the elver fishing season (3/22), and were fished five days per week from Sunday noon to Friday noon. These nets were removed on 5/23, eight days before the end of the elver fishing season (5/31) and two days before the last effective fishing period (evening 5/25 to morning 5/26), because the catch had decreased to less than a few grams of eels (i.e., < 50 eels). Net 3 was set on 3/22, and was fished daily until 5/26, except when high runoff from West Harbor Pond collapsed the net or required it to be pulled to one side of the culvert. Net 3 was not fished until the next spring tide in June, as was done in 1999, because tide charts indicated the tidal hight would not reach 11 ft.

All nets were tended five days per week (Monday through Friday). The eels in each net were removed, taken to the DMR laboratory for processing, and then released into West Harbor Pond approximately 100 ft above net 3 to minimize the chance of recapture. In the laboratory, bycatch was removed, and the catch in each net was weighed. Environmental data including air temperature, sea temperature, wind speed, precipitation and tidal heights were obtained from the DMR laboratory. Water temperature in the pond was monitored with a automated datalogger (HOBO). Beginning in mid-May, alewives which swam up the fishway were blocked from entering West Harbor Pond by net 3. These fish were counted and passed upstream, providing the only assessment of the alewife run into West Harbor Pond.

On 5/5, when tidal height was scheduled to exceed 11 ft, DMR personnel planned to quanitify the efficiency of "escapement" net 3 by using dip nets to capture eels that were able to migrate past this net. DMR personnel arrived at the site approximately one hour before high water, and remained approximately three fours after high water, but the tidal height did not reach 11 feet, and flow in the fishway never reversed. Therefore, we assumed the efficiency of net 3 was 95.5%, the value determined for the same net, set in the same way at the end of the study in 1999. To compensate for this efficiency, the actual daily catches in net 3 were multiplied by 1.045.

Results

All three nets combined captured 80,349.6 g of glass eels (weight adjusted for net 3 efficiency) at West Harbor Pond from 3/22 to 5/26. Net 1 captured approximately 7%, net 2 approximately 83%, and net 3 approximately 11% of the total glass eel harvest at this site (Table 4). Although nets were fished for the entire season, 75% of the glass eels were caught in a 25-day period from 3/23 to 4/21 (Fig. 2). The largest catches occurred during the first seven fishing days when sea surface temperature in the harbor ranged from 4.5-5.8°C and the surface water temperature of the pond ranged from 6.3-8.4°C. As in 1999, there was a negative correlation between catch in nets 1 and 2 and sea surface temperature and pond surface temperature.

Discussion

Two conclusions can be drawn from this study at West Harbor Pond. First, nets set closer to the head-of-tide catch more fish than those set farther downstream. In both years, the catch in net 1 (after adjusting for differences in net size), was about 60% of the catch in net 2. Therefore, restricting nets from the head-of-tide is a valid conservation measure. Second, in some locations a single net can be very efficient. The West Harbor Pond research site probably represents a worst-case scenario because net 2 was set close to the head-of-tide, and eel migration into fresh water above this point was restricted by a dam and fishway designed for adult anadromous fish.

The first conclusion is supported by additional information from the Pemaquid River. On April 18, 1999, commercial harvesters Pat Bryant, Paul Bryant, and Milton Tibbets set two nets above the falls (legal head-of-tide) with the permission of DMR. The next day, catch in these two nets was 8.75 pounds while total catch in nets below the legal head-of-tide was reported to be 3.83 pounds.

Elver upstream passage and recruitment monitoring

Introduction

Juvenile eels, known as glass eels or elvers depending on the degree of pigmentation, migrate into Maine's coastal waters in the spring. Some elvers remain in estuarine habitat, but many attempt to migrate to growth habitat in inland waters. Natural and man-made obstacles, such as hydropower dams, may prevent or delay the upstream migration. Two management plans, Maine's *American Eel (Anguilla rostrata) Species Management Plan* and the Atlantic States Marine Fisheries Commission's *American Eel Fisheries Management Plan*, call for 1) maintaining and enhancing eel abundance in all watersheds where they now occur, 2) restoring eels to waters where they had historical presence but may now be absent, and 3) providing adequate upstream passage and escapement into inland waters of elvers and eels. Migration of eels past dams and other obstacles must be improved to accomplish these goals.

During the Federal Energy Regulatory Commission (FERC) licensing process, the owner of a hydropower facility consults with resource agencies to determine appropriate fish passage measures. Once the license is issued, the operating conditions are fixed for the licensing period, typically 30-50 years. Since 1997, DMR has been requesting upstream and downstream passage for eels at appropriate hydropower projects during the licensing process.

The *Lower Kennebec River Comprehensive Hydropower Settlement Accord*, signed prior to the removal of Edwards dam in Augusta, requires that Kennebec Hydro-Developers Group (KHDG) dam owners and DMR undertake a three-year research project to study upstream and downstream passage measures for eels at the seven KHDG facilities. Three of the facilities are located on the Sebasticook River and four on the mainstem Kennebec River. In addition to these sites, DMR initiated a study of upstream passage at the Veazie Dam on the Penobscot River with the cooperation of PPL Maine, LLC; the National Marine Fisheries Service; and the Penobscot Indian Nation. The primary objective of this study was to determine where juvenile eels pass or attempt to pass upstream at each of the hydropower facilities. Secondary objectives were to determine the timing of the upstream migration, the magnitude of the migration, and the size distribution of the migrants.

Methods

In 2000, upstream passages were installed at five of the seven KHDG facilities (Fig. 3) and at the Veazie Project. A full-length passage was designed, built, and installed at the Fort Halifax project and one portable passage was installed at each of five additional projects (Benton Falls, Lockwood, Hydro Kennebec, Shawmut, and Veazie). A full-length passage was used at Fort Halifax because of study results in 1999, when the number of migrating eels far exceeded the capacity of the portable passages that had been installed.

The passage at **Halifax** (Fig. 4A) was two feet wide, four inches deep and included an 8.75-foot ramp parallel to the dam, angled at 30°; a two-foot level resting area; a 16-foot ramp extending from the resting area to the top of the flashboards, angled at 43°; an eight-foot ramp extending over the headpond, angled at 10°; a collection chute made of flexible tubing and stovepipe; and a collection box. Because electricity was not available on the south side of the dam, a hydro-ram pump supplied attraction water. Approximately two gallons minute^{-1} were delivered to the top of the collection chute and eight gallons minute^{-1} were supplied to the lower end of the ramp about two feet above the resting area. Climbing substrate (Enkamat 7220 flatback) was stapled to the bottom of the passage along its entire length.

Portable passages were installed at the remaining sites. At four sites, the passage was a self-supporting wooden ramp, six feet long, one foot wide, and four inches deep (Fig. 4B); a shorter two-foot ramp was used at the Shawmut project. Climbing substrate was stapled to the bottom of the passage, and an aluminum cover was added to reduce predation. The ramp of each passage was angled at approximately 35°. Eels that used the passage were captured and retained alive in a bucket suspended from the top of the passage. A siphon hose in the headpond delivered two to five gallons minute^{-1} of water to the passage. Half of the water was directed down the passage to attract eels, and the other half was used to wash eels from the top of the passage into the capture bucket.

Installation of the passage at the south side of the **Fort Halifax** Dam began on 6/5, after flashboards were erected, and was completed on 6/21. The passage was operational until 7/28, when attraction water was discontinued due to shortage of staff. It was restarted on 8/15 and operated until 8/22. Catches from 6/21-6/29 are probably underestimated because eels were able to escape from the collection box. The pump supplying attraction water stopped working sometime during the night on 7/6 and again on 7/15.

The passage at **Benton Falls** originally was installed on 6/29, approximately 100 feet south of the dam in a secondary channel created by spill over the flashboards. It was moved to a location immediately below the east side of the dam (Fig. 4B) on 7/14 on the basis of nighttime observations made on 7/12. The catch from 7/17 may be underestimated because a snapping turtle had taken up residence beneath the passage entrance overnight. The passage was operated until 7/28, when attraction water was discontinued. It was operated again from 8/15-8/24.

At the **Lockwood** project, a portable passage was installed on 7/7, the day the flashboards were erected. FPLE installed taller flashboards (sheets of plywood) on the east side of the spillway, as requested by DMR. However, when the headpond was refilled, leakage under the plywood completely inundated the passage and prevented its redeployment. On 7/14, FPLE personnel reduced the leakage with a plastic tarpaulin and retrieved the passage. The following day, the mainstem Kennebec River received three inches of rain and the passage was washed away. By the time it was safe to work below the dam, the upstream eel migration had nearly ceased and a new passage was not deployed.

A passage was installed 6/27 at the **Hydro Kennebec** project above the western side of the tailrace. It operated until 7/28, except for 6/27, 7/17, 7/21, and 7/26, when either high water rendered the passage inoperable or algae blocked the siphon hose and stopped the attraction water. It was restarted on 8/14 and operated until 8/24.

Because equipment must be carried a considerable distance, a short portable passage was set up at the **Shawmut** project on 6/29, below the eastern side of the dam where spill enters the main channel of the river. The passage was rendered inoperable by spill and reset on three consecutive days (7/5-7/7). Flashboards were lost at the Shawmut project following three inches of rain on 7/15 and the passage could not be reset for the remainder of the month. By the time flashboards were replaced, the upstream eel migration had nearly ceased at other locations and the passage was not redeployed.

The passage at **Veazie** was installed on 6/22 in the abandoned fishway on the east side of the river, the same location where a portable passage was installed in 1999. It was operated until 7/28.

In general, passages were operated continuously and tended daily, Monday through Friday. Occasionally, a passage was tended on the weekend if large numbers of eels were migrating. If the number of eels captured at a project was less than 150, all eels were counted and total weight recorded. If catches exceeded 150, all eels were weighed and the number estimated from subsamples. Approximately every 10 days, subsamples of 100 eels each were weighed and measured and these were used to estimate numbers of eels in large catches. After biological data were recorded, eels were released above each dam into the headpond. Environmental data were also recorded daily.

Results

An estimated 81,626 migrating eels were passed at **Fort Halifax** in 2000, an 86% decrease compared to 1999 (Table 5). Although different methods were used in the two years, nighttime observations indicated that the enormous numbers of eels seen in 1999 did not materialize in 2000. Approximately 90% of the eels moved upstream within a 30-day period (Fig. 5A), similar to the pattern seen in 1999. The size distribution in the two years was similar; eels ranged from 80-199 mm total length, but most were 105-109 mm (Fig. 6A). During a nighttime visit to the site, DMR personnel observed that eels accumulated along the base of the dam (southern 220 feet), presumably attracted by leakage under the flashboards. As in 1999, very few were seen on the face of the dam.

Approximately 37,207 eels used the passage at **Benton Falls** during a 10-day period (Fig. 5B), more than twice the number passed in 1999 (Table 5). The apparent difference in the migration pattern in the two years (protracted in 1999, contracted in 2000) may be the result of using different types of gear deployed in different locations. The size distribution was similar to the previous year; eels ranged from 85-170 mm, but most were 105-109 mm (Fig. 6B). Eels apparently swim along the main channel of the river until they reach the dam and then ascend the ledge to the highest pool on its eastern side. During a nighttime visit, DMR personnel observed eels climbing the ledge below the dam with apparent difficulty, judging by their slow progress.

Approximately 6,462 eels used the passage at the **Hydro Kennebec** project in 2000, representing a tenfold increase from 1999 (Table 5). The eels appeared in a very short five-day pulse between 7/24-7/28 (Fig. 5C), 17 days after flashboards were installed at Lockwood and 10 days after heavy rainfall. This pattern was very different than in 1999, when the migration period was protracted. The size distribution of eels in 2000 was not the same as that in 1999. The 2000 distribution was bimodal with a major peak at 105-109 mm and a minor peak at 115-119 mm (Fig. 6C); in 1999, the distribution was unimodal with a peak at 100-104 mm.

Late installation of the flashboards, leakage under the boards, and spill over the boards at **Lockwood** prevented timely installation of the passage and no eels were captured at this location. During the drawdown on 7/7, DMR personnel inspected the base of the dam from the eastern shore to the Winslow/Waterville bridge looking for concentrations of stranded eels. They were found along this entire length of spillway, although it appeared that smaller eels were more abundant on the east side of the spillway, and larger eels were more abundant along the canal wall.

At the **Shawmut** project, a total of 19 eels used the passage from 6/29-6/30. These eels were not measured.

A total of 5,681 eels used the passage at **Veazie**, a 72% decline compared to the previous year (Table 5). In addition, the size distribution of eels was different in the two years. In 2000, the distribution was unimodal with a peak at 80-84 mm, but in 1999 the distribution was bimodal with a major and minor peak at 60-64 mm and 80-84 mm, respecitively. It is possible that the entrance to the abandoned fishway was partially blocked by a large piece of borken concrete in 2000.

Discussion and Recommendations

The appropriate location of upstream passage for American eel has been determined for the Fort Halifax and Benton Falls projects. At Halifax, the passage should be placed on the southern side of the dam, against the retaining wall. The design developed by DMR probably can accommodate passage of 100,000 eels, but whether it can accommodate 500,000 is not certain. Leakage under the flashboards should be decreased to facilitate attraction of eels to the passage entrance. In addition, filling the small pool (approximately 5' x 5') below the resting area would eliminate stranding of eels. At Benton Falls, the passage should be placed on the eastern side of the dam, against the retaining wall. Leakage under the flashboards should be decreased to facilitate attraction of eels to the passage entrance.

In 2001, nighttime visual observations will be used at Burnham, Lockwood, Hydro Kennebec, Shawmut, and Weston to overcome difficulties in setting up passages.

Downstream passage of silver eels

Introduction

Adult eels, known as silver eels, migrate in late summer and fall from Maine's inland waters to the sea to spawn. Two management plans, Maine's *American Eel (Anguilla rostrata) Species Management Plan* and the Atlantic States Marine Fisheries Commission's *American Eel Fisheries Management Plan*, call for 1) maintaining and enhancing eel abundance in all watersheds where they now occur, 2) restoring eels to waters where they had historical presence but may now be absent, and 3) providing adequate upstream passage and escapement into inland waters of elvers and eels. Migration of eels past dams and other obstacles must be improved to accomplish these goals.

During the Federal Energy Regulatory Commission (FERC) licensing process, the owner of a hydropower facility consults with resource agencies to determine appropriate fish passage measures. Once the license is issued, the operating conditions are fixed for the licensing period, typically 30-50 years. Since 1997, DMR has been requesting upstream and downstream passage for eels at appropriate hydropower projects during the licensing process.

The *Lower Kennebec River Comprehensive Hydropower Settlement Accord*, signed prior to the removal of Edwards dam in Augusta, requires that Kennebec Hydro-Developers Group (KHDG) dam owners and DMR undertake a three-year research project to study downstream passage measures for eels at the KHDG facilities, three of which are located on the Sebasticook River and four on the mainstem Kennebec River. The primary objectives of this study were to determine the seasonal and diel timing of the downstream migration of adult eels, the behavior of migrating adult eels at hydropower facilities, and the efficiency of existing downstream passage measures for adult eels.

Methods

The study was conducted at the **Benton Falls** Project and the **Fort Halifax** Project on the Sebasticook River (Fig. 3). The Benton Falls dam is located approximately 5.2 miles above the Fort Halifax dam, and the latter is located 1400 feet above the confluence of the Sebasticook and Kennebec Rivers. Eels used for study were obtained from a commercial eel harvester whose weir is located on Twenty-Five Mile Stream, approximately two miles downstream of Unity Pond. Twenty-Five Mile Stream enters the Sebasticook River approximately 14 miles above the Benton Falls project.

Radio telemetry equipment was installed and calibrated at the two sites between 8/14 and 9/26. Three automated scanning receivers (Model SRX-400, Lotek Engineering, Newmarket, Ontario, CA) were deployed at Benton Falls and seven (same model, provided by FPLE) were deployed at Halifax to record the passage of radio-tagged eels. Three types of antennas (9-element Yagi, 6-element Yagi, and "dropper") were used to monitor different areas at each project. Yagi antennas were deployed above the water surface, while dropper antennas (coaxial cable with distal 18" of insulation removed) were inserted inside braided nylon line or 1" plastic pipe and deployed underwater. One antenna was connected to each scanning receiver unless otherwise stated. In general, antennas were deployed and gain settings were adjusted so they would detect signals in a particular area, with little overlap between antennas.

At **Benton Falls**, one 6-element Yagi was used to monitor the turbine intake area and a second to monitor the headpond immediately above the spillway and gates; these two antennas were attached via a switcher to a single receiver. A third 6-element Yagi monitored the water immediately below the spillway and gates (spill and main channel). One dropper antenna was deployed in the drop-box of the downstream bypass and another was installed in the draft tube of the smaller turbine. The larger turbine was undergoing repair during the entire study and was not monitored this year.

At **Fort Halifax**, a 9-element Yagi monitored an area from several hundred yards above the dam to the railroad bridge below; a 6-element Yagi monitored the headpond between the safety line and the dam; these antennas were attached to a single receiver via a switcher. A third 6-element Yagi scanned the water immediately below the spillway and above and below the Obermeyer gate. One dropper was placed in each of the two turbine intakes and in each of the two draft tubes. A final dropper was deployed in the bypass; however, current speeds through the bypass were so high that the probability of detecting a tag was about 33%.

Only downstream migrating female eels were used in this study because their large size ($\geq$400 mm) makes them particularly susceptible to turbine injury or mortality. Eels to be radio-tagged were removed from the weir and individually placed into a cooler containing a solution of Eugenol for five to ten minutes to anaesthetize them. A small ventral incision was made approximately 1¾" anterior to the vent and a 16-gauge needle was inserted about ½" posterior to the incision. The radio tag was inserted into the incision and the tag antenna trailed from the body cavity through the small puncture left by the needle. The incision was sutured and treated with betadine. The coded radio tags (Model MCFT-3CM, Lotek Engineering, Newmarket, Ontario, CA) were 11 mm in diameter, 36 mm long, weighed 5.9 g in air and 2.6 g in water, and had a typical operation life of 100 days. The tags emitted a coded signal every five seconds at 149.480 MHz.

A total of 12 eels were tagged and released on three dates during the study (Table 6). Five eels (#16-20) were tagged at the weir on 9/26 between 8:30-10:30AM, and were released at 5:45PM in the Benton Falls headpond, approximately 0.5 miles upstream of the dam, where the Rt. 139 bridge crosses the river. A second group of five eels (#23-#27) were tagged at the weir on 10/19 between 8:30-10:30AM, and released at 11:30AM from the public access area immediately below the Benton Falls Dam. The two final eels (#28-29) were transported in air from the weir on 11/8 to the University of Maine at Orono, held in well water for five hours, tagged, transported in air to Benton Falls, and released at 5:45PM in the Benton Falls headpond; these eels were tagged as a demonstration during a workshop.

Data from the scanning receivers usually were downloaded daily during the week and notes were made on the operating conditions at each of the two projects. Water temperature was measured and recorded six times a day at a depth of 10 feet at the Fort Halifax project and the weir site (HOBO data logging thermometer).

Results

Water flow in the Sebasticook River was low during the study as a result of few rain events through the late summer and fall. Instantaneous stream flow rarely exceeded the mean daily stream flow (based on 68 years of record for USGS gauge 01049000), except for the period from 9/16 to 10/11. Because of low flow and concerns about out-migrating alewives, the eastern (upstream) turbine at Fort Halifax was not operated during the study period and the western turbine was only operated from 9/29-10/6, 11/1-11/3, and on 11/16. The large turbine at Benton Falls was undergoing repairs during the study period, and the small turbine was operated from 9/27 to 11/5.

Average daily water temperature in the river at Fort Halifax ranged from 16.8-7.3°C during the study period (9/26-11/16). During this same period, water temperature at the weir on Twenty-Five Mile Stream ranged from 13.7-4.5°C. Rainfall during the study period occurred on 10/18.

Of the seven eels released above Benton Falls, only one (14%) did not attempt to migrate downstream. This eel (#20) was detected just once near the intake approximately three hours after its release (Table 7). On 10/11 and 10/26, DMR personnel attempted to locate the tag from a boat with a data logger/receiver and directional loop antenna. An intermittent signal was detected in the headpond on both occasions, but its location could not be determined with accuracy and recovery was not attempted. This eel is not discussed further.

The six remaining eels were detected at the Benton Falls Dam from 1.8-557 hours (0.1-23.2 days) after being released (Table 7). The time from release to arrival was not related to release date, i.e., eels tagged later in the season did not move faster. The time from arrival to passage ranged from 0.05-213.07 hours (0.001-8.88 days). Four eels (57%) passed through the small turbine, one (14%) used the bypass, and one (14%) passed over the gates or spillway. One of the eels (#29) passed through the turbine when it was not operating and was detected 11.51 hours later at Fort Halifax. DMR personnel attempted to locate the other three eels that had passed through the turbine when it was operating and had apparently not survived (#16, 18, and 19). Two tags were detected in deep water below the tailrace, but were not recovered.

The five eels released immediately below the Benton Falls Dam arrived at the Fort Halifax Project from 5.09-16.40 hours after being released (Table 8). Four of them (80%) passed the dam either via the Obermeyer gate or bypass; neither turbine was operating when these eels passed. The fifth eel (20%) remained near the Obermeyer and bypass for several days and moved upstream before contact was lost. Two of the eels (#26 and 27) covered the five miles between the dams in approximately five hours and passed the Halifax Dam within two hours of arrival. The other two eels (#24 and 25) took about twice as long to arrive and did not pass for about two days.

Three of the eels that were released above Benton Falls and successfully passed the dam (#17, 28, 29) were contacted at Fort Halifax. These eels arrived from 11.51-20.72 hours after passing Benton Falls and passed Halifax from 0.67-67.22 hours after arriving. Eel (#17) passed via the Obermeyer or bypass when the downstream turbine was operating; the other two passed when neither turbine was operating.

Near the two projects, migrating eels were mostly active at night (Tables 9, Table 10). The number of contacts made during darkness ranged from 56-100%, and all but one of the eels (#29) passed during darkness. The higher number of daytime contacts at Fort Halifax may be an artifact of the antenna (9-element Yagi) and gain settings. Two eels moved during the day; eels #26 and 27 were released below Benton Falls at 11:30AM and were detected at Fort Halifax between 4 and 5PM.

Discussion and Recommendations

Four of seven eels above Benton Falls passed via the turbines (57%), one used the bypass (14%), one passed over the gates or spillway (14%), and one did not pass. Three of the eels that passed through the turbine were never detected at Fort Halifax, and were either killed, injured, or ceased migrating. One eel that passed when the turbine was not operating continued its migration. Before passing, eels were alternately detected in rapid succession by the antenna monitoring the intake and the antenna monitoring the headpond above the gates and spill. Some overlap in pickup between these two antennas occurred near the gate and pier in the middle of the dam, and eels were probably in this location (east of the east bypass entrance). Passage might be improved if the easternmost gate was opened at night.

Passage at Fort Halifax could not be evaluated in 2000 because the project was not generating during most of the study period. Eels did spend a considerable amount of time in the immediate vicinity of the turbine intakes, the bypass entrance, and the Obermeyer gate. In 2001, an antenna will be deployed in or near the Obermeyer gate to determine whether eels use the gate or the bypass.

Elver enforcement

Marine patrol officers in each division worked fewer hours on elver enforcement in 2000 than any previous year, reflecting the low fishing effort during the season (Table 11). Division I officers spent more time on elvers than Division II officers. Summonses and warnings decreased by approximately 70% compared to the previous year (Table 11, Table 12).

Coastal and inland eel fishery

Each year the Department of Marine Resources obtains harvest information from eel fishermen on a voluntary basis. A total of 52 licenses and permits were issued in 2000 for the coastal eel pot, inland eel pot, and inland weir fisheries (Table 13). Seven of the harvesters (13%) reported a total catch of 14,349 pounds of eels.

The estimated harvest of eels in Maine, from inland and coastal waters, has varied enormously from a high of 400,130 pounds in 1912 to a low of 8,764 pounds in 1984. The average annual harvest for the period from 1887-1997 is 96,167 pounds. Catches exceeded the long-term average from 1900-1933 and from 1975-1980 (Fig. 8). However, the peak in catch in the late 1970s was not as pronounced nor as long-lived as the peak in early 1900s.

Atlantic States Marine Fisheries Commission

Three public hearings on the Atlantic States Marine Fisheries Commission (ASMFC*) Draft American Eel Fisheries Management Plan* were held in Maine during 1999, and the plan was accepted in November. To remain in compliance with the plan, each member state must conduct an annual young-of-year (YOY) survey for glass eels, and must require reporting of harvest by commercial fishermen beginning in 2001. The American Eel Technical Committee met during January 2000 to finalize the protocol for the YOY survey, which was accepted by the Management Board. In 2000, DMR promulgated rules that require commercial eel pot fishermen to report harvest, and DIFW made reporting a permit condition for ommercial eel weir and eel pot harvesters in inland waters.

Relicensing of Hydropower Projects

The Department currently is consulting on 20 hydropower projects in Maine that are being relicensed or are conducting fish passage studies. The location and status of these projects is summarized in Table 14.

Table 1. Status of 25 research, monitoring, and enforcement needs. These were identified by the Eel and Elver Management Fund Committee in 1996-1997. The number preceding each item does not indicate priority.

Research, monitoring, and enforcement needs	Status
01 Work with eel/elver industry to develop legislation/regulations	DMR ongoing
02 Comment on hydropower licenses to improve eel passage	DMR ongoing
03 Obtain harvest, effort, fishing location for all eel fisheries	DMR ongoing
04 Characterize population structure (size, sex ratio, age, growth)	UM completed
05 Model impacts of dams on reproductive potential	UM completed
06 Determine trophic role of eels in freshwater and efficiency of weirs	UM completed
07 Assess bycatch of elver fishery	DMR ongoing
08 Determine level of escapement of elvers from fishery	DMR completed
09 Maintain enforcement in elver fishery	DMR ongoing
10 Design and test upstream passage, obtain recruitment data	DMR ongoing
11 Determine downstream mortality/behavior of adult eels at dams; obtain data from tailrace studies	DMR ongoing
12 Determine extent, size, and timing of the spring run of adult eels and environmental correlates of migration	Contract completed
13 Determine extent, size, and timing of the fall run of adult eels and environmental correlates of migration	DMR ongoing
14 Determine age and growth of elvers in estuaries	UM completed
15 Determine behavior of elvers at dams (time before ascending)	
16 Determine growth rates and movements in inland waters; determine impact of inland pot fishery for yellow eels	UM/DIFW completed
17 Determine effectiveness of diversion techniques for eels at dams	
18 Determine effect of eel stocking in areas where eels have declined	
19 Locate DIFW stocking sites (prior to selecting sampling sites)	DMR ongoing
20 Collect information of eel aquaculture	DMR ongoing
21 Determine why are eels scarce/absent from some areas	
22 Determine why some areas have big elver runs but no big eels	
23 Set up review schedule for research	
24 Map locations of dams & eel populations (to prioritize projects)	USFWS completed
25 Determine effect of pollutants on eels (chlorine, PCBs, dioxins etc)	DMR assisting DEP
26 Conduct annual young-of-year (YOY) survey	DMR ongoing

Table 2. Number of licenses by gear type and residency for the elver fishery, 1996-2001. A maximum of 1868 people legally fished for elvers in 1995 (prior to legislation requiring an elver fishing license). No nonresident licesenses were sold in 2000 or 2001.

	Resident						Nonresident			
License type	1996	1997	1998	1999	2000	2001	1996	1997	1998	1999
1 fyke	34	22	41	33	24	33				
2 fykes	50	55	61	272	263	175		1	1	1
3 fykes	6	6	64							
4 fykes	5	6	8							
5 fykes	37	25	27					1	1	
1 fyke + dip	362	202	344	225	204	138	1		4	
2 fykes + dip	318	223	307						2	
3 fykes + dip	61	40	237				1	1	2	
4 fykes + dip	20	23	51							
5 fykes + dip	198	127	271				4	8	7	
Dip net	1,107	655	882	213	174	113	3	4	4	
Total	2,198	1,384	2,293	743	665	459	9	15	21	1

Table 3. Harvest and effort for the elver fishery, 1977-2000.

Year	Harvest (pounds)	Number of licenses	Number of fyke nets	Number of dip nets	Total number of nets
2001		459	521	251	772
2000	2,625	665	754	378	1,132
1999	3,587	744	804	438	1,242
1998	14,360	2,314	3,806	2,111	5,917
1997	7,360	1,399	1,844	1,283	3,127
1996	10,193	2,207	2,632	2,075	4,707
1995	16,599	≤ 1,868			
1994	7,374				
1978	16,645				
1977	22,000				

Table 4. Summary of harvest by net for the elver escapement study. Pigmented eels were less than 6". The number of alewives passed, an estimate of the West Harbor Pond run, is also included.

Species, life stage, and net	2000	1999
Total weight of glass eels in net 1 (actual g)	5,443.7	6,428.9
Total weight of glass eels in net 2 (actual g)	66,447.7	47,706.1
Total weight of glass eels in net 3 (actual g)	8,094.0	10,769.9
Total weight of glass eels in net 3 adjusted for efficiency (g)	8,458.2	12,499.5
Number of pigmented eels in net 1	334	81
Number of pigmented eels in net 2	1,901	153
Number of pigmented eels in net 3	1,732	268
Number of alewives passed	4,270	

Table 5. Summary of upstream eel migration during 2000 and 1999 field seasons.

	2000		1999	
Project	Operation dates	Number of eels passed	Operation dates	Number of eels passed
Ft. Halifax	6/21-7/28; 8/15-8/22	81,628	6/4-9/15	551,262
Benton Falls	6/29-7/28; 8/14-8/24	37,207	6/22-9/16	14,335
Hydro-Kennebec	6/27-7/28; 8/14-8/24	6,462	7/5-9/16	683
Shawmut	6/29-6/30	19	-	-
Veazie	6/22-7/28	5,681	5/23-9/8	19,713

Table 6. Summary of the tag and release date, size of tagged eels, and release location for the 2000 telemetry field season.

Date tagged and released	Tag number	Eel total length (mm)	Release location
9/26	16	852	Benton Falls headpond, Rt 139 bridge
9/26	17	890	Benton Falls headpond, Rt 139 bridge
9/26	18	920	Benton Falls headpond, Rt 139 bridge
9/26	19	842	Benton Falls headpond, Rt 139 bridge
9/26	20	958	Benton Falls tailrace
10/19	23	846	Benton Falls tailrace
10/19	24	852	Benton Falls tailrace
10/19	25	876	Benton Falls tailrace
10/19	26	894	Benton Falls tailrace
10/19	27	795	Benton Falls tailrace
11/8	28	750	Benton Falls headpond, Rt 139 bridge
11/8	29	666	Benton Falls headpond, Rt 139 bridge

Table 7 Time of release, arrival, and passage for radio-tagged silver eels at the Benton Falls Project during the 2000 field season. The turbine was operating from 9/27-11/5.

	Release		Arrival at dam		Passage at dam				
Tag	Date	Time	Date	Time	Date	Time	Release to arrival (hr)	Arrival to passage (hr)	Route
16	9/26	1745	09/27	2217	10/6	1922	28.5	213.07	turbine
17	9/26	1745	10/01	0236	10/1	239	104.9	0.05	bypass
18	9/26	1745	10/19	2247	10/19	2327	557.0	0.66	turbine
19	9/26	1745	9/26	2353	9/26	2358	6.1	0.08	turbine
20	9/26	1745	9/26	2059	NA	NA	3.2	NA	didn't pass
28	11/8	1745	11/8	1930	11/9	0505	1.8	9.58	spill
29	11/8	1745	11/12	1953	11/15	2213	98.1	74.34	turbine

Table 8. Time of release, arrival, and passage for radio-tagged silver eels at the Fort Halifax Project during the 2000 field season. Turbines were operating from 9/29-10/6, 11/1-11/3, and on 11/16.

	Release or pass BF dam		Arrival at dam		Passage at dam				
Tag	Date	Time	Date	Time	Date	Time	Release to arrival (hr)	Arrival to passage (hr)	Route
17	10/1	0239	10/1	2153	10/2	1933	19.23	21.66	gate/bypass
23	10/19	1130	10/20	354	NA	NA	16.40	NA	didn't pass
24	10/19	1130	10/20	133	10/21	1913	14.05	41.67	gate/bypass
25	10/19	1130	10/20	059	10/22	105	13.49	48.11	gate/bypass
26	10/19	1130	10/19	1635	10/19	1808	5.09	1.56	gate/bypass
27	10/19	1130	10/19	1725	10/19	1828	5.93	1.05	gate/bypass
28	11/9	0505	11/10	149	11/12	2102	20.72	67.22	gate/bypass
29	11/15	2213	11/16	944	11/16	1024	11.51	0.03	gate/bypass

Table 9. Total number of contacts and nighttime contacts made with radio-tagged silver eels at the Benton Falls Project during the 2000 field season. IN = turbine intake; 6 UR = headpond above the gate and spillway; BY = bypass; 6 DR = channel below the gate and spillway; TR = tailrace.

	Number of contacts					Contacts during
Tag	IN	6 UR	BY	6 DR	TR	darkness
16	342	514	0	14	1	92%
17	5	0	2	0	0	100%
18	21	17	0	0	2	100%
19	14	4	0	0	1	100%
20	1					100%
28	53	80	0	8	0	100%
29	55	42	0	7	7	100%

Table 10. Total number of contacts and nighttime contacts made with radio-tagged silver eels at the Ft. Halifax Project during the 2000 field season. 9 UR = headpond to RR bridge; 6 UR = headpond near intakes; E IN = east (upstream) turbine intake; W IN = west (downstream) turbine intake; N OUT = north draft tube; S OUT = south draft tube; 6 DR = below spillway and above and below Obermeyer gate.

	Number of contacts							Contacts during
Tag	9 UR	6 UR	E IN	W IN	N OUT	S OUT	6 DR	darkness
17	814	0	1	4	29	0	95	64%
23	7,413	2	189	1,216	0	0	138	72%
24	1,290	2	0	75	0	0	61	63%
25	3,141	3	0	0	5	1,685	115	75%
26	258	1	5	217	0	0	18	81%
27	197	0	8	21	0	0	70	100%
28	7,872	3,128	14,862	17	15	552	196	56%
29	2,991	211	0	13	1	0	73	41%

Table 11. Summary of Marine Patrol activities, 1996-2000.

	Division I					Division II				
Category	1996	1997	1998	1999	2000	1996	1997	1998	1999	2000
Eel enforcement hours	2,664	3,134	3,516	1,554	587	1,569	2,354	2,749	757	467
Overtime hours	1,075	844	776	337	29	734	539	540	104	0
Summonses issued	67	113	73	5	2	80	101	131	8	2
Verbal and written warnings	64	93	145	23	5	55	95	119	10	5
Complaints addressed	148	205	248	39	1	104	219	132	4	0

Table 12. Summary of elver fishery violations, 1996 –2000.

	Division I Warnings					Division I Summonses					Division II Warnings					Division II Summonses				
Violation	96	97	98	99	00	96	97	98	99	00	96	97	98	99	00	96	97	98	99	00
Closed season, harvesting										1			4		4			4		
Closed season, locating nets													1	1				1		2
Closed season, setting gear				2	3				1	1			1					1	1	
Closed season, net size								2					11					13		
Closed period, harvesting		33	15	6			33	24	1			25	19	1			16	43	5	
Closed area, fishing for elvers			9	1				2					4	2				6		
Closed area, 150' fishway			6				26	2				5	6				7	8		
Closed area, middle third	27	32	47	7	1	21	13	15			26	31	51	3	1	34	23	66	2	
Closed area, dipping in fyke	1	2				5	2	4					4	1				8		
Closed area, alewife trap							1						1					1		
Fishing method, limits on gear			11	3				2					8					10		
Fishing method, from boat			2																	
Fishing method, standing in water	19	6	5			17	12	12			12	10	10			30	24	22		
Molesting elver gear	6	4	1	2		7	4	2			3	1	1			6	3	3		
Fishing without license	7	7	2		1	9	9	3	2		7	10	1	1		7	4	4		
Untagged elver nets	4	8	5	2		4	6	4			5	13	9	1		1	18	13		
Theft						4		1			2					6		1		
Miscellaneous		1					7										6			
Total	64	93	103	23	5	67	113	73	4	2	55	95	131	10	5	84	101	204	8	2

Table 13. Eel pot licenses issued by Department of Maine Resources (DMR) and eel pot and weir permits issued by Department of Inland Fisheries and Wildlife (DIFW).

Year	Number DMR licensess	Number DIFW permits	Total licenses and permits
2000	25	27	52
1999	26	42	68
1998	41	79	120
1997	53	74	127
1996	48	71	119
1995	no data	124	124
1994	55	51	106
1993	39	60	99
1992	33	80	113
1991	32	56	88
1990	29	34	63
1989	19	25	44
1988	17	22	39
1987	14	16	30
1986	12	23	35
1985	28	23	51
1984	30	24	54

Table 14. Status of hydroelectric projects being relicensed in Maine. Dam number refers to relative position in the river (e.g. the dam at Veazie is the first dam on the Penobscot River encountered by a fish migrating from the ocean).

River system	Dam number	Project name	Location	Status
Penobscot	1	Veazie	Veazie	Consulting
	2	Great Works	Old Town	Consulting
	4	Howland	Howland	Consulting
	6	Medway	Medway	New license with eel measures
Kennebec	1	Lockwood	Waterville/Winslow	DMR studies in 2000
	2	Hydro-Kennebec	Hydro-Kennebec	DMR studies in 2000
	3	Shawmut	Fairfield	DMR studies in 2000
	4	Weston		DMR studies in 2000
	5	Abenaki	Madison	Consulting
	6	Anson	Madison	Consulting
Sebasticook	1	Ft Halifax	Winslow	DMR studies in 2000
	2	Benton Falls	Benton	DMR studies in 2000
	3	Burnham	Burnham	DMR studies in 2000
Presumpscot	3	Saccarappa	Westbrook	Consulting
	4	Mallison	Gorham/Windham	Consulting
	5	Little Falls	Gorham/Windham	Consulting
	6	Gambo	Gorham/Windham	Consulting
	7	Dundee	Gorham/Windham	Consulting
	9	Eel Weir	Standish/Windham	Consulting
Salmon Falls	1	South Berwick	South Berwick	Consulting

Figure 1. Map of West Harbor Pond research site.

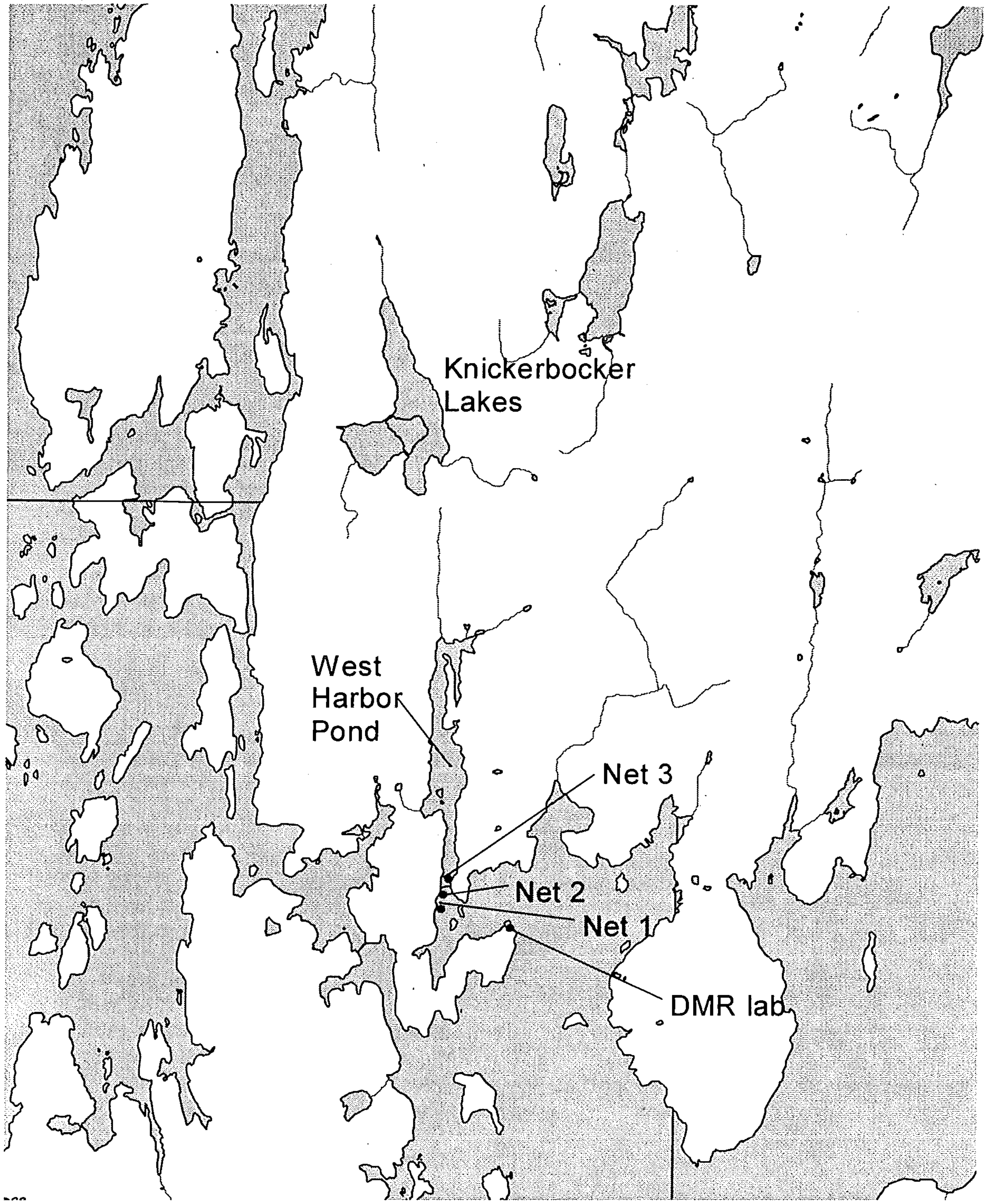


Figure 2. Daily harvest of glass eels at West Harbor Pond.

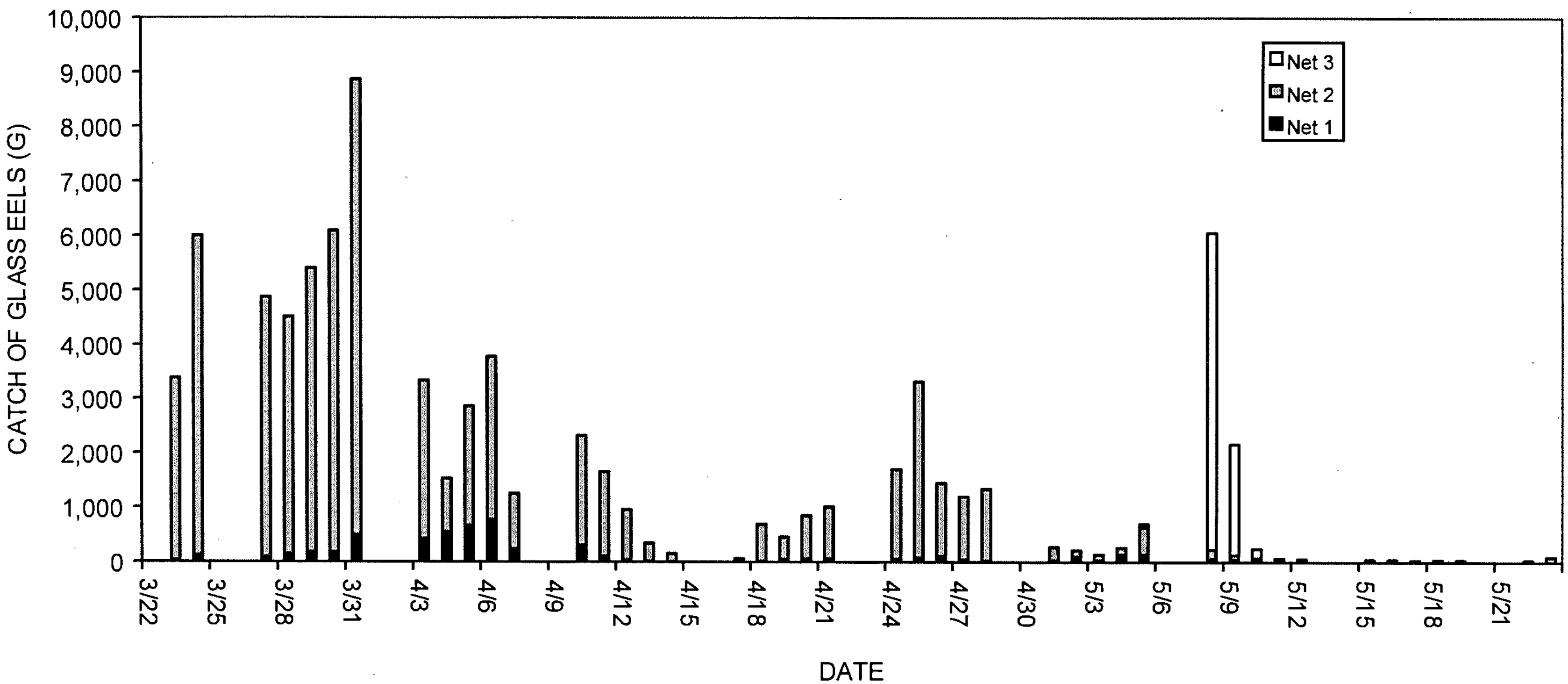


Figure 3. Location of dams on the Kennebec River and Sebasticook River. The seven KHDG dams are starred.

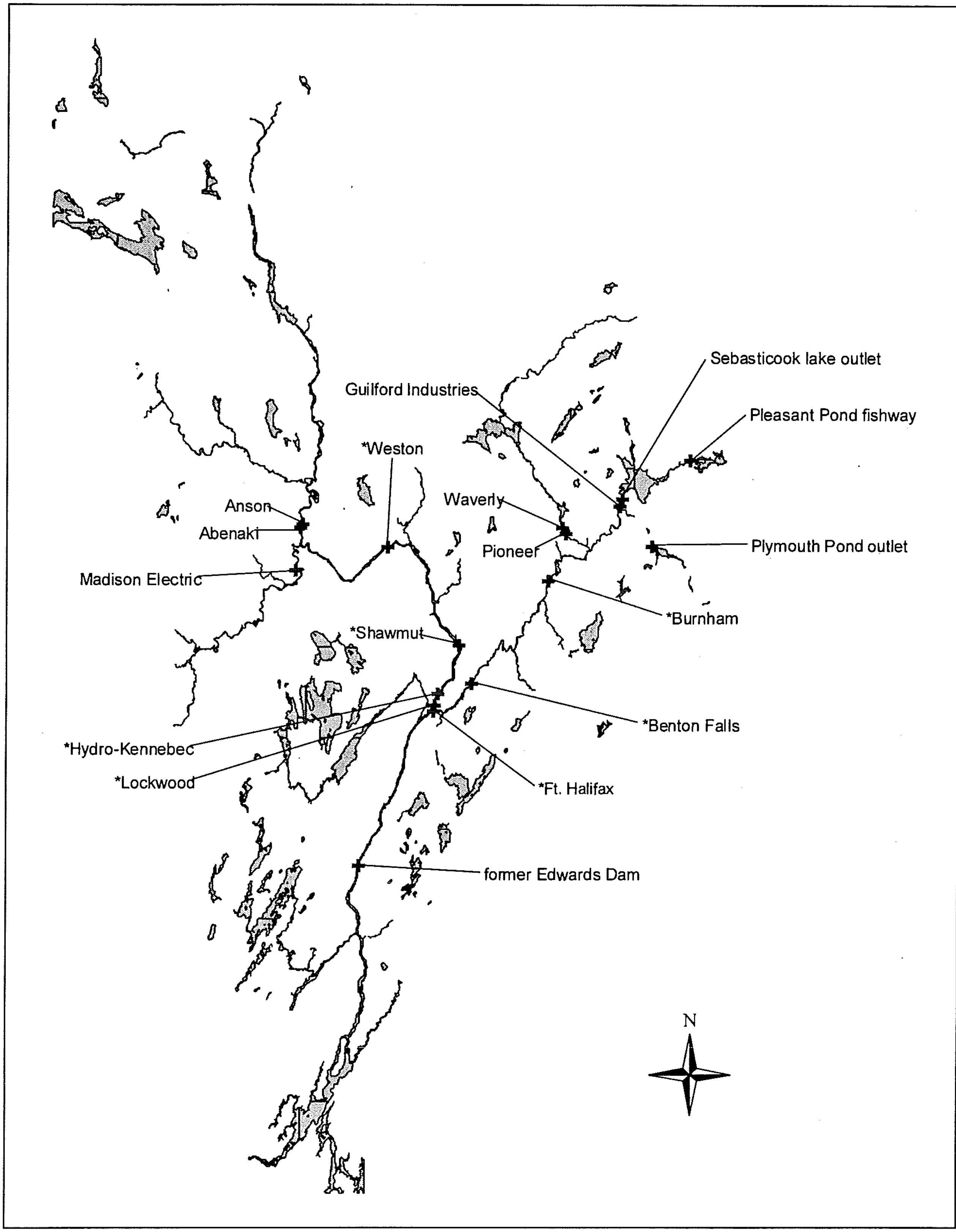
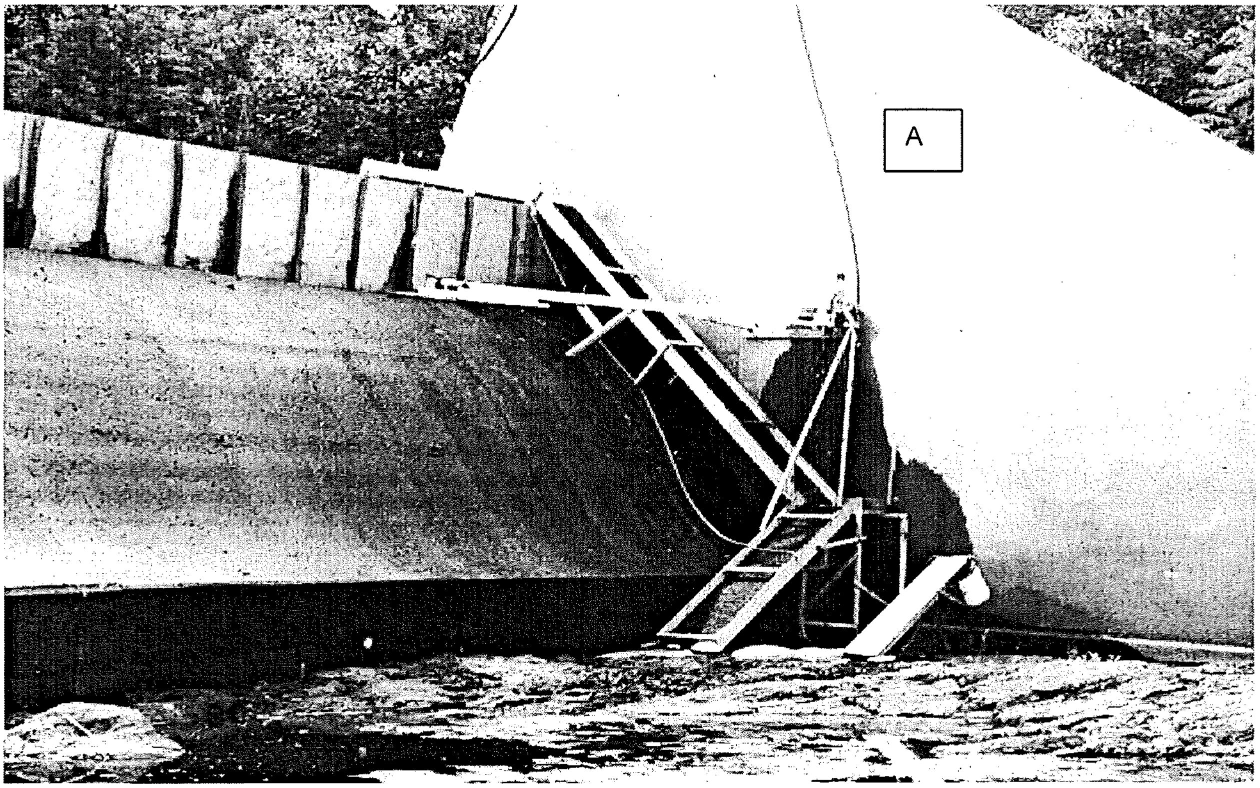


Figure 4. Upstream eel passages at the (A) Ft. Halifax dam and (B) Benton Falls dam. A portable passage is shown next to the full-length passage at Ft. Halifax.



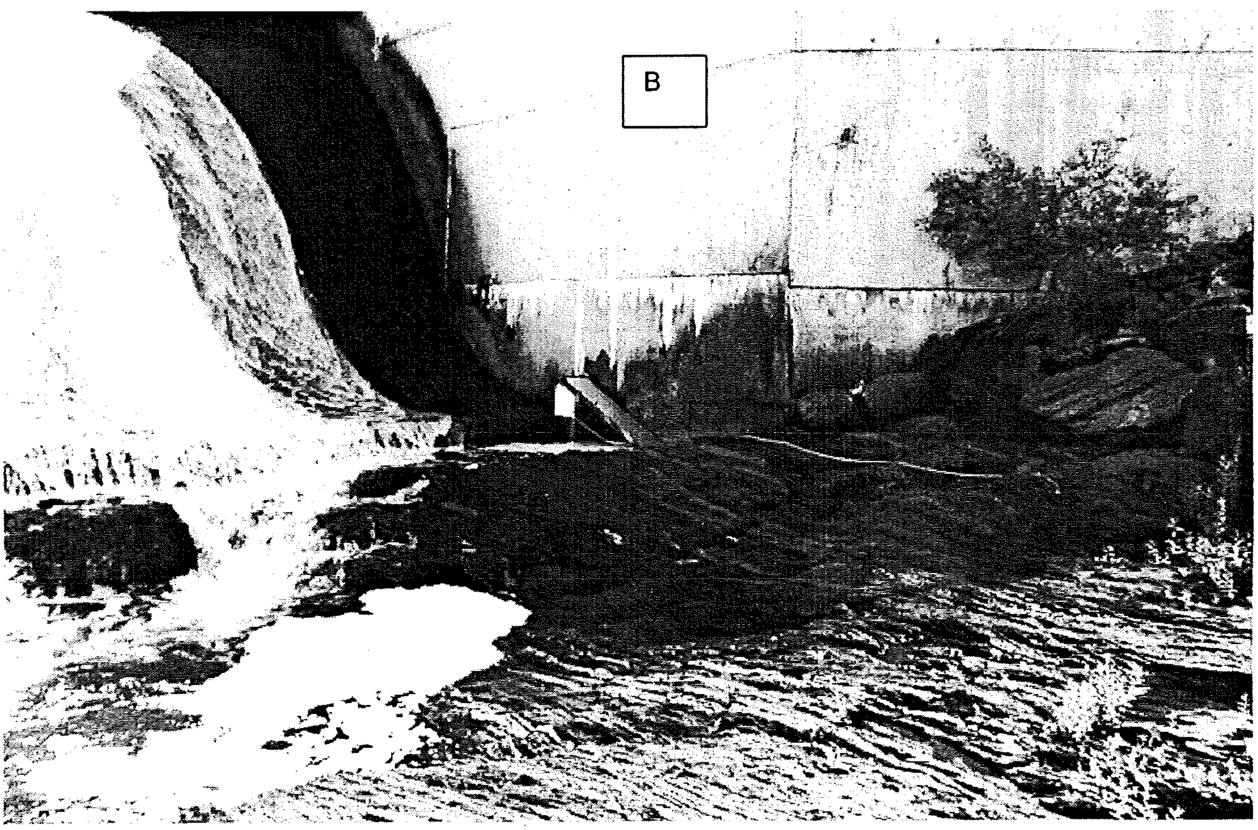


Figure 5. Upstream passage of American eel during the 2000 field season at the (A) Ft. Halifax dam, (B) Benton Falls dam, and (C) Hydro-Kennebec dam. Note change in scale on Y-axis in (A).

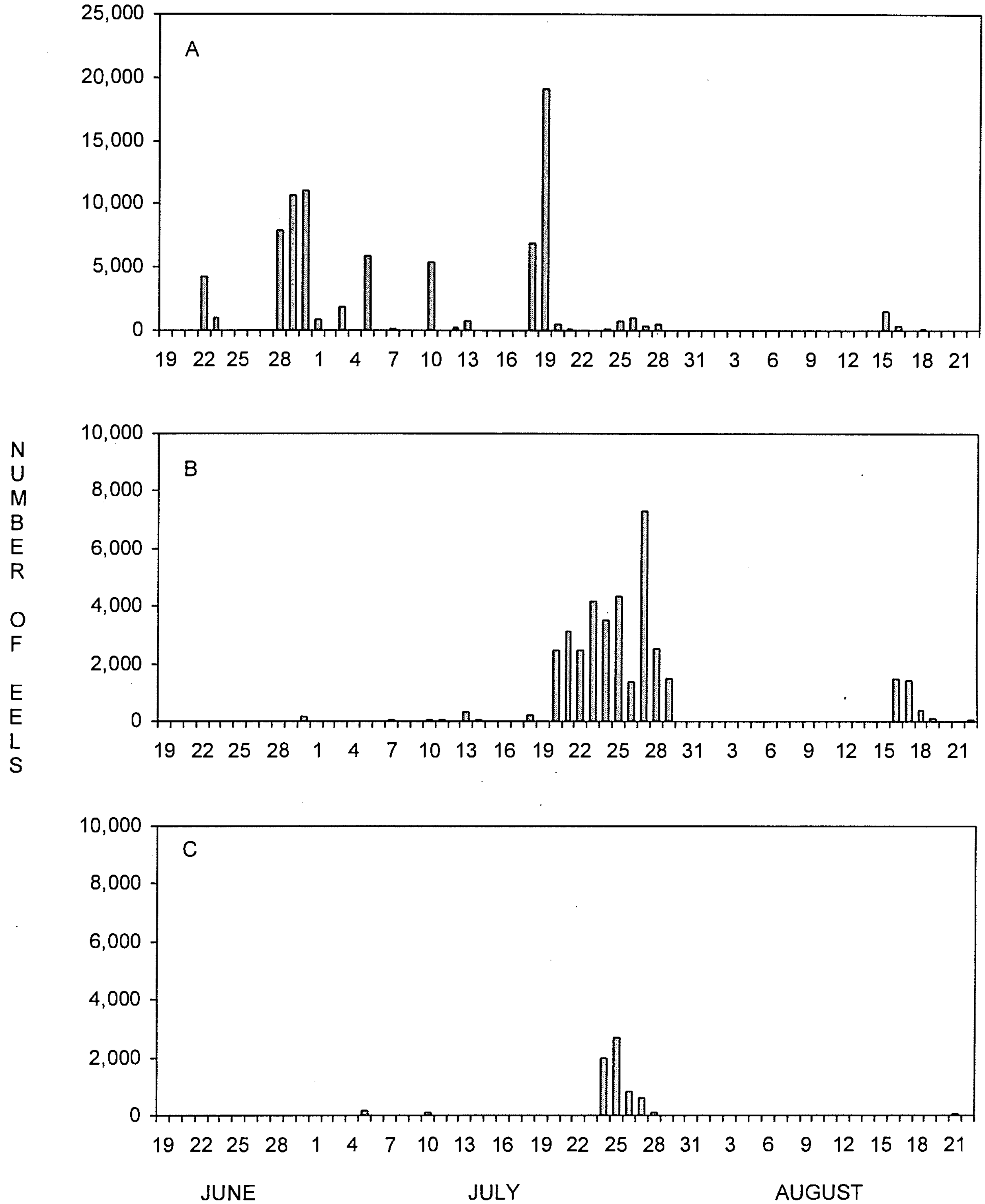


Figure 6. Length distribution of upstream migrating American eel during the 2000 field season at the (A) Ft. Halifax dam, (B) Benton Falls dam, and (C) Hydro-Kennebec dam.

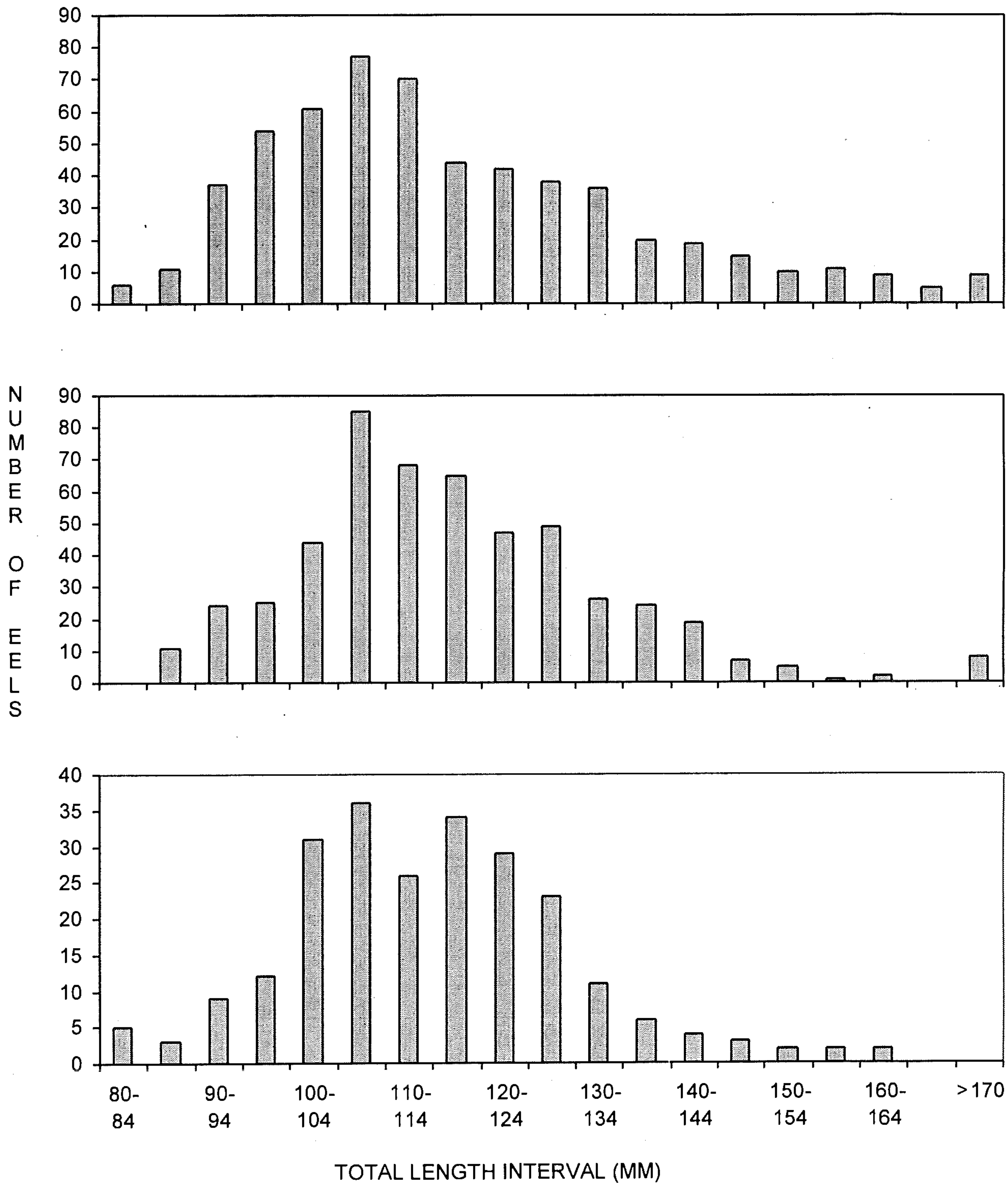


Figure 7. Upstream passage (A) and length distribution (B) of migrating American eel during the 2000 field season at the Veazie dam.

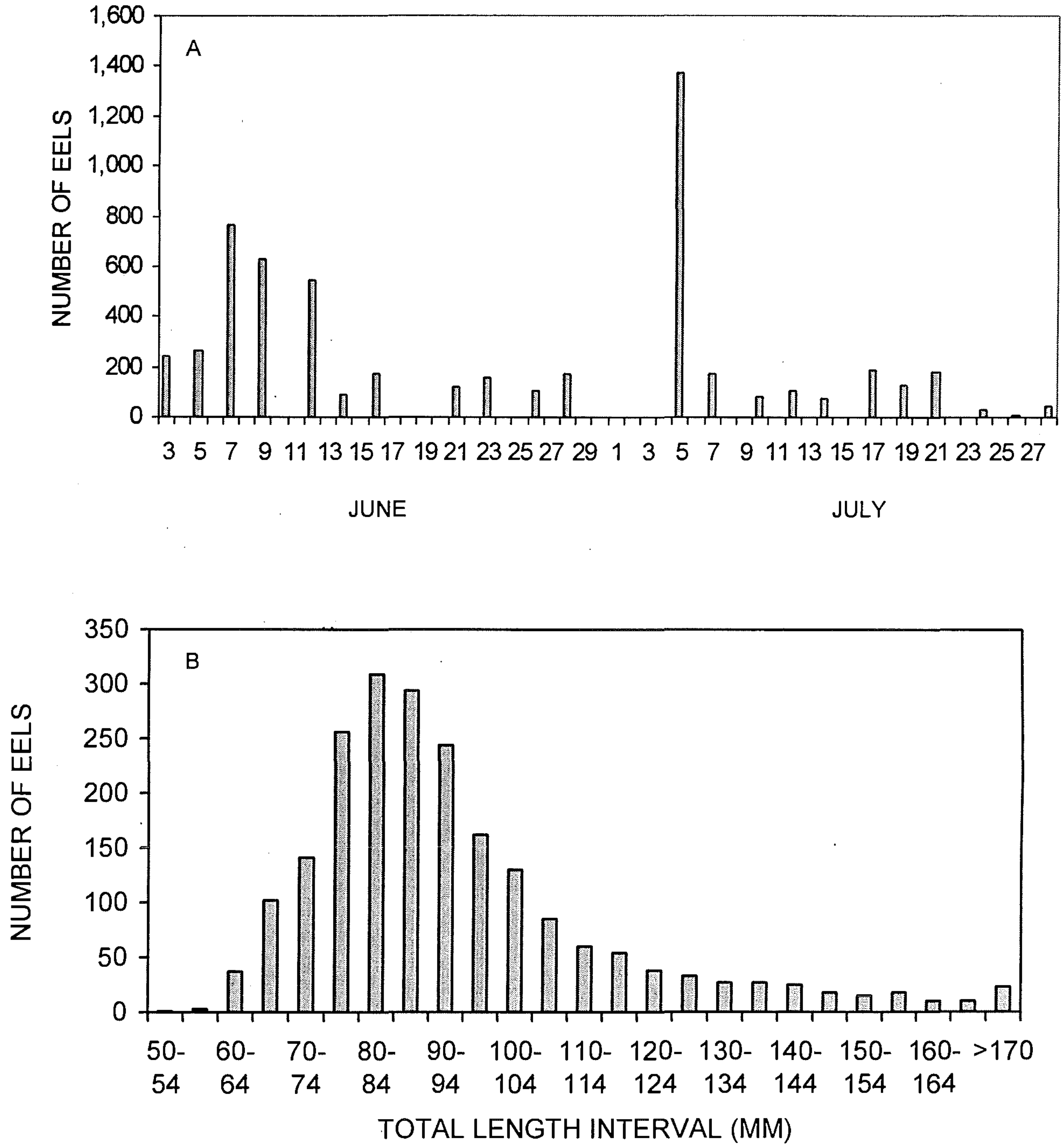
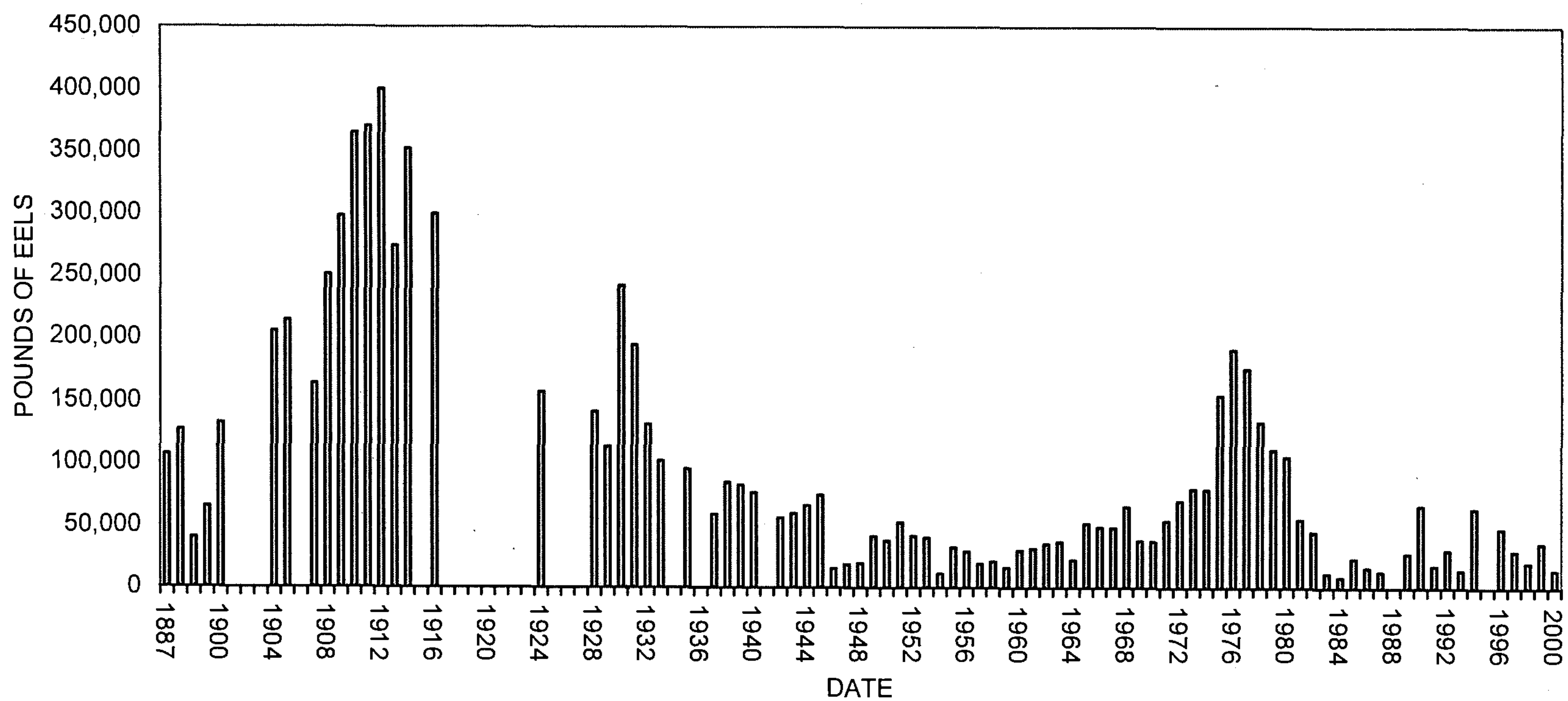


Figure 8. Landings of American eel in Maine.



Factors affecting daily and seasonal habitat use of lacustrine yellow-phase American eel populations

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Introduction

American eels (Anguilla rostrata) are often considered as ecological generalists occupying a wide array of aquatic habitats (Facey 1987). However, 'ecological generalism' is highly contingent upon the scale of analysis. Therefore, what may be construed as generalist tendencies at one observational scale may not be the case under closer scrutiny. Population analyses may overshadow important or necessary habitat associations at the individual level.

A few researchers have studied eel movements and habitat usage in riverine (Bozeman 1985; Oliveira 1997; Baras 1998), estuarine systems (Parker 1997) and in lacustrine systems (LaBar 1983; LaBar 1987). However, none have simultaneously compared eel behavior, movements or ecological performance among varying habitat types and locations. Many terrestrial studies have shown differences in activity patterns or home range sizes in accordance with habitat quality. Similarly, in aquatic systems, Benke (1985) showed differences in species richness and abundance with habitat differences within a Georgia river. Can similar ecological patterns be observed for a generalist fish species, the American eel?

In Maine, eels inhabit lacustrine systems that vary in size, productivity, community structure and temperature regime. What behavioral shifts or concessions must a population make in order to survive and grow in such varying local environments? In addition, do individuals 'prefer' particular habitat regimes within their lake or home range, or is anywhere adequate for the apparently generalistic eel?

Methods

Anesthesia, surgical implantation and activity

To address these questions, I undertook a radiotelemetry approach incorporating global positioning systems (GPS) and geographic information systems (GIS) technologies. Initially, a method of anesthesia and surgical implantation of radio transmitters was developed. In spring 1998, I experimented with MS-222 and eugenol to determine the best anesthetic regime for eels. Results show no significant difference between eugenol and MS-222 for induction time to surgical anesthesia (Fig. 1). Although eugenol treatments have longer recovery times than do MS-222 (Fig. 2), this is often beneficial for surgical cases.

To familiarize myself and field crews with radiotelemetry techniques, and to determine daily and seasonal behavioral patterns, I radio-tagged resident eels of Hermon Pond, Maine in May (n=20) and August (n=20) 1998. Eels were implanted with Lotek model MBFT-4 radio transmitters (11 mm diameter, 3.7 g weight in water). We tracked eels over 24 hr periods from May 1998 through October 1998 and continued daytime tracking until February 1999. Eels were tracked with a Lotek model SRX 400 telemetry receiver. Eel locations were recorded with a Garmin GPS II+ unit at the loudest signal strength at zero gain on the telemetry receiver. At each eel observation point, GPS coordinates, time, depth and activity were recorded. Although eel activity declines during daylight hours (Fig. 3), continued diurnal activity warrants a complete 24-hour cycle for habitat use observations.

Determining Habitat Use
Spring and summer habitat usage

Eels from four sites representing different habitat categories were implanted with radiotransmitters in May 1999 (Table 1). Eel locations were recorded weekly in each lake or pond on a 30-hr continuous tracking cycle through August 1999. Eel locations again were determined with a Lotek SRX 400 telemetry receiver at a gain of zero. GPS coordinates and time were recorded with a Garmin GPS II+ GPS receiver. Depth, surface temperature, and other fish presence were recorded with a Humminbird 3-D view fish finder. In areas of poor bottom visibility, vegetation type (emergent or submergent) and quantity, substrate composition (rock, mud, sand, etc) and degree of cover were estimated using the fish finder. If the bottom was visible, these variables were visually estimated. In addition, each lake or pond was equipped with Onset temperature data loggers programmed for hourly observations. Loggers were positioned at the bottom and midwater locations of the lake's deepest point. Daily changes in water level were recorded by a meter stick attached to a post set at an unobtrusive nearshore region of each lake. In addition, daily weather observations, sunrise, sunset, moonrise and moonset times were recorded.

Fall and winter habitat usage

Six eels from Hermon Pond and eight from Swan Lake were implanted with radio transmitters in September 1999. Day and night observations were recorded through October and daytime observations continued to be gathered two to three times weekly through April 2000. Many of the same habitat variables continued to be recorded (with the exception of the fish finder usage).

Habitat use analysis

Two separate analyses will be performed to compensate for differences in scale. For population level habitat use, I will use categorical analysis and logistic regression to determine use differences according to lake or pond. Each location differs in overall habitat categorization (Table 1) and I want to know if eels are targeting particular areas of the lake. If so, which variables tend to be driving their overall choices? To determine habitat selection at the individual level, I will plot each eel's locations in relation to the geographic features of the lake or pond. Then, by calculating the eel's home range (by minimum convex polygon), I can quantify all habitat types available to that individual within her range. I will use compositional analysis (Aebischer 1993) to determine individual selection for habitat types. Using GIS for this analysis gives the added benefit of possibly identifying other important variables not previously considered in an eel's decision making. Also, GIS allows for easy sorting and blocking of data for analysis of selection at particular times or seasons.

Current status

All fieldwork for constructing landscape scale habitat maps of each location was completed in 2000. Additionally, all eel point locations and home ranges have been incorporated into GIS tables. In the GIS, a 100 m grid layer was constructed for each location and centroid GPS coordinates for each grid cell were determined. Depth, vegetation type and quantity, substrate type and bottom contour were estimated for each grid centroid either through fish finder estimation or visualization in shallower areas. I am currently constructing and digitizing depth, vegetation and substrate map layers for each lake or pond. These layers will be incorporated into GIS maps of the lakes or ponds with layers of the home ranges of the radiotagged eels and point locations of each eel observation for the population and individual analyses of habitat relationships.

Population demographics

Survival, growth, and population density

Because all radio transmittered eels (n = 68) exceed the 400 mm length cutoff that differentiates the sexes, I assume they are female (Oliveira, K., pers. comm). However, I am curious to see if behavior is affected by population density. In 1999, I conducted a mark/recapture protocol for each site to estimate eel population density. Many terrestrial studies have shown alterations in home range size or activity patterns in compensation for varying population densities. Are eels similarly affected?

All captured eels (regardless of size) from each site were freeze-branded with individual marks beginning in May 1999 and extending through October. Eels were captured with eel pots constructed with ½ inch mesh. Pots were tended daily and baited with live earthworms. Eels were anesthetized with eugenol (80 mg/10 L) and numeric brands were applied to the left anterior dorsal surface. In addition, length and weight were recorded prior to release at the capture site. Each lake was potted for one week each month and recaptures were recorded and length and weight measurements were again recorded. Data was analyzed with Program MARK to determine monthly population (Pollock's Robust Design, G. White, Colorado State University) and seasonal survival estimates (Cormack-Jolly-Seber model, Program MARK, G. White, Colorado State University). Seasonal growth also will be calculated for each site. Each site will be categorized according to population density (low, medium, high) if significant differences occur and density will then be entered into the habitat use analyses as another variable. Each location was tested further for differences in home range size and daily activity patterns.

Results and current status

Eel Abundance and Density

Monthly abundance per location was estimated with Pollock's Robust Design in Program MARK. This model estimates abundance based on derived estimates of survival, emigration, immigration and recapture probabilities. This model is very sensitive to capture method. Therefore abundance estimates derived by this method reflect numbers of actively foraging eels per trap night (Table 2). Density was calculated as estimated abundance divided by surface acreage of each location (MapInfo GIS, UTM 83, Zone 19). Because of poor model fit and outrageously high standard errors, I am currently pursuing other methods of analyzing this dataset. However, the results do show an interesting pattern of changing abundance for the year of trapping in each location. Abundance estimates are highest in June and July, crash in August, increase again in September and then steadily decline through the fall and winter months (Figure 4). Again, I believe this pattern to be a direct effect of this modeling method that estimates the numbers of actively foraging catchable eels and is quite conservative in its estimation. This pattern is similarly reflected in my recorded activity of telemetered eels where activity drastically declines in August and September. Interestingly, there is no significant difference between eel densities for the four locations (one-way ANOVA, $F = 2.8$, $p = 0.07$). (Could this be a reflection of carrying capacity? Hmm, very interesting!!)

Survival

Seasonal survival was determined for telemetered eels by using the Cormack-Jolly-Seber (CJS) population model in Program MARK. This model estimates survival based on the probability of resighting for a given time period. Weekly observations of telemetered eels were recorded to estimate the probability of surviving and remaining within the study area for the duration of the observation period (Table 3). As expected, seasonal survival is high for larger-sized ($n = 68$, mean length = 587 ± 8 mm, mean weight = 406 ± 24 g) female yellow eels not subjected to an active commercial fishery.

Growth

Although I did recapture marked individuals throughout the study, I have yet to get to seasonal growth analysis.

Home Range Size

Home range size of radio-telemetered yellow eels was determined by calculating a minimum convex polygon (MCP) in MapInfo of all observations per individual in each location. Summer home range sizes do not significantly differ among the four locations (one way ANOVA on natural log transformed data, $F = .63$, $p = 0.6$). However, there is a significant difference between the winter range sizes of eels in Hermon and Swan lakes (t-test on natural log transformed data, $t = 6.6$, $p = 0.0$) with eels in Hermon Pond having much larger ranges (mean size = 67.6 acre vs. mean size = 1.9 acre in Swan).

At this time with many analyses yet to go, I believe this difference to be attributed to overall warmer water temperatures, hence greater winter activity, in Hermon Pond vs. Swan Lake. This difference may also be attributed to eels periodically having to move to new locations within Hermon Pond because of winter hypoxia issues. An observed general pattern with Hermon Pond winter eels was a periodic small-scale movement to a new spot and then not moving for a while. Alternatively, Swan Lake eels, once positioned in a location for the winter, did not move until spring.

Activity

Activity was recorded for each radio-telemetered eel at each observation (n = 1404). All observations were additionally categorized to the hour and season. Frequency of active eels (Figure 5) resembles a familiar pattern in eel activity with most activity occurring between 8 PM and 6 AM. However, Hermon Pond eels stray from the norm and significantly differ from the other populations in activity pattern (χ^2 = 91.6, 33 df, p = 0.00). This divergence from the typical eel behavioral pattern is mirrored by Hermon Pond eels in frequency of inactive observations by hour ((χ^2 = 51.7, 33 df, p = 0.02).

I am currently pursuing further analytical methods for this dataset. I believe that such broad-based assumptions may not hold up under closer scrutiny. I am currently pursuing more powerful analytical means (logistic regression) for this dataset to tease apart the relationships among population, season, time and the non-independence of observations per eel.

Future Plans

A dissertation should be completed by December 2001.

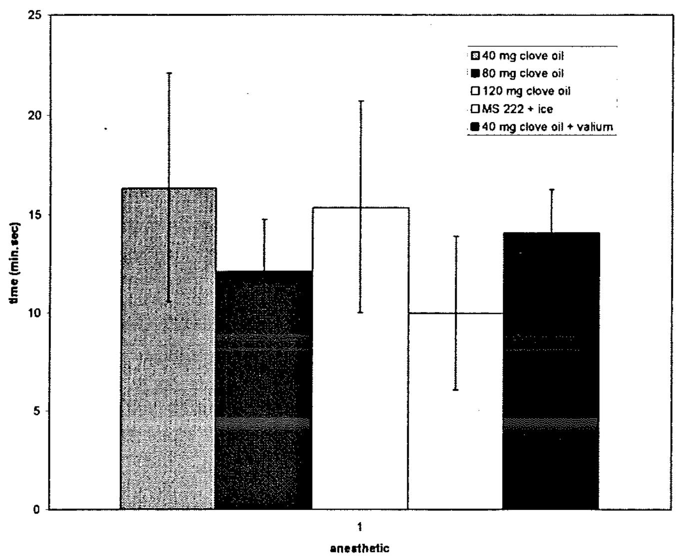

Figure 1. Induction time (min.) for anesthetic regimes tested on American eels. Sample sizes were 10 eels per treatment and values are mean ± SD.

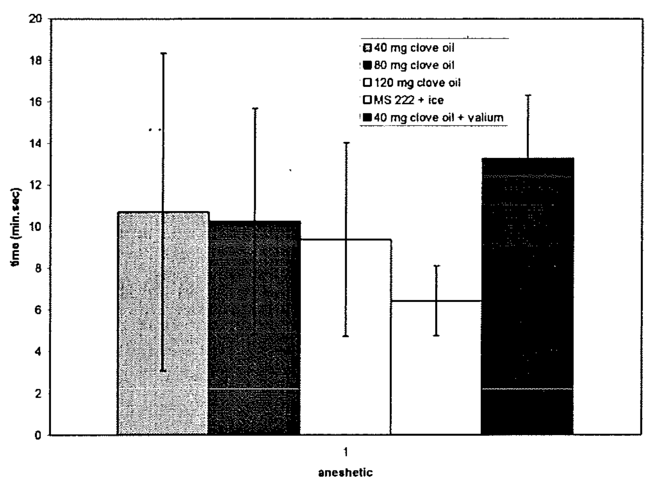

Figure 2. Recovery time (min.) for anesthetic regimes tested on American eels. Sample sizes were 10 eels per treatment and values are mean ± SD

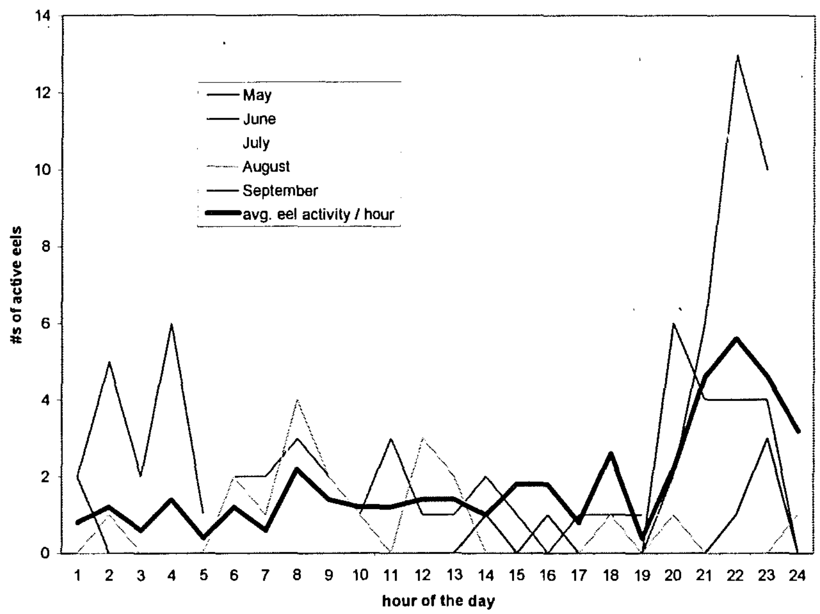

Figure 3. Hourly activity for 20 radiotransmittered Hermon Pond, ME eels from May to September 1998.

Table 1. Four study locations for determining daily and seasonal habitat use in American eels

Name	County	Acreage	Max. depth (ft.)	Productivity	Fish community type
Hermon Pond	Penobscot	461	17	eutrophic	warmwater
Davis Pond	Penobscot	417	14	mesotrophic	warmwater
Brewer Lake	Penobscot	881	48	mesotrophic	warmwater/coldwater
Swan Lake	Waldo	1370	87	oligotrophic	coldwater

Table 2. Derived monthly abundance (N), standard error (SE), and density estimates of actively foraging American eels in four freshwater Maine lakes.

Location		May 1999	June 1999	July 1999	August 1999	September 1999	October 1999	November 1999	May 2000
	N		1083	687	159	317	211		396
Swan	SE		636	411	110	200	140		246
Lake	Density (eels/acre)		0.79	0.5	0.12	0.23	0.15		0.29
	N	113		496	174		134	54	228
Brewer	SE	53		236	91		73	35	115
Lake	Density (eels/acre)	0.13		0.56	0.20		0.15	0.06	0.26
	N		991	222	64	386	32		698
Hermon	SE		627	162	59	252	37		460
Pond	Density (eels/acre)		2.15	0.48	0.14	0.84	0.07		1.51
	N	64	74	74		74			86
Davis	SE	43	56	56		56			64
Pond	Density (eels/acre)	0.15	0.18	0.18		0.18			0.21

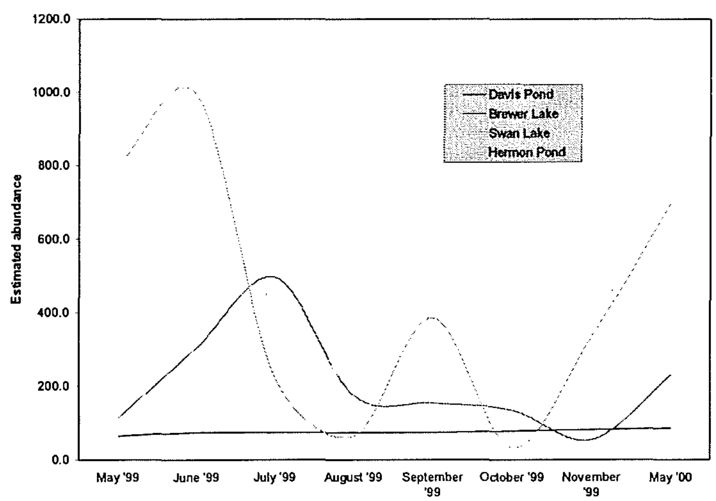

Figure 4. Estimated numbers of actively foraging catchable eels by location.

Table 3. The probability of resident survival (± SE) for radiotagged yellow eels in four Maine lakes

Season	Swan	Brewer	Hermon	Davis
Spring	0.94 (0.078)	0.99 (0.008)	0.81 (0.144)	0.99 (0.008)
Summer	0.99 (0.016)	0.99 (0.008)	0.99 (.009)	0.99 (0.008)
Fall	0.90 (0.051)		0.99 (0.004)	
Winter	1.0 (0.000)		0.97 (0.04)	

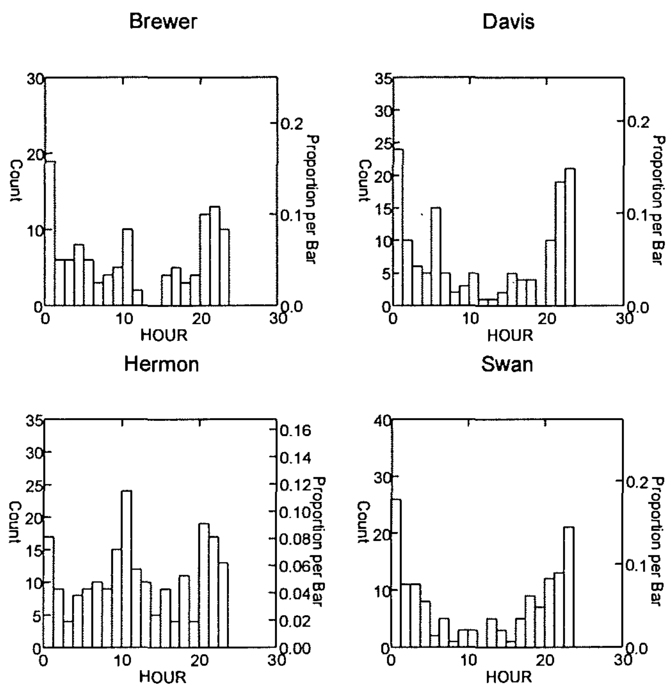

Table 5 . Frequency of active radio-telemetered eels per hour for four Maine lakes from May 1999 – April 2000 (0 = midnight, 12 = noon).

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Density, biomass, and commercial freshwater pot fisheries for American eels in Maine.

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Abstract

Little data are available on densities and there are no data on harvest efficiencies or recovery rates of American eels (*Anguilla rostrata*). We examined population densities, biomass, harvest efficiencies, recovery rates, and population characteristics of American eel (>270 mm) in five Maine lakes and one river during 1998 and 1999. Delury population estimates were obtained at three locations where eels were removed (two lakes) or commercially harvested (one river section). Schnabel estimates were calculated for the other three lakes. Densities of eels ranged from 2.1 to 8.4 eels/ha (o.52 to 1.86 kg/ha) in the lakes, and was 32 eels/ha (8.9 kg/ha) in the river section. Commercial pots harvested large portions of the American eel populations with harvest efficiencies ranging from 36 to 95%. Locations with higher densities tended to have higher harvest efficiencies. Two lakes were resampled one year after the simulated harvest to estimate recovery of their American eel populations. One year post-harvest American eel populations were low at both lakes, and catch per unit effort dropped over ten-fold. Mean length of eels differed between one lake and the river (ANOVA, $p < 0.05$, df = 5, 2667). All locations had high proportions of females (67 to 89% of the eels measured). High harvest efficiency and high proportions of females could exacerbate recently documented decreases in American eel recruitment.

Introduction

Researchers have noticed recent declines in American eel populations (*Anguilla rostrata*) (Castonguay et al. 1994a; Richkus and Whalen 1999). Concurrent declines in European eel (*A. anguilla*) stocks suggest that conditions in the Atlantic ocean may be partly responsible (Castonguay et al. 1994b). Anthropogenic factors (e.g. commercial harvesting, hydroelectric projects, agriculture) may exacerbate population declines caused by environmental conditions. Over-harvesting has been linked to declines in other North Atlantic fish stocks (e.g. Myers et al. 1996).

Several life history characteristics make American eels particularly difficult to manage. Anguillid eels are long-lived, often taking 8 to 10 years to mature (Helfman et al. 1987); therefore, changes in American eel stocks can take years to be reflected in harvest data. American eel is a catadromous species and individuals are thought to spawn once, then die (Helfman et al. 1987). Consequently, all harvest mortality occurs prior to reproduction. They are also panmictic (Tesch 1977), and northern latitudes may have higher proportions of female eels than southern latitudes (Helfman et al. 1987). Population declines in northern latitudes could cause drastic declines to this species throughout its range. Because of their broad geographic range (Lee 1980), managing this species across national and international borders is complex and often difficult. All of these factors must be considered to properly manage this species.

Currently, the State of Maine allows American eels to be harvested at four life stages: elver, glass, yellow, and silver (sexually mature). In 1999, Maine licensed 28 commercial pot fishers. They were allowed to harvest yellow and silver eels in inland waters without restrictions on number of commercial pot fishers, season, locations fished, or amount of gear deployed. Commercial pot fishers were restricted to using pots, with additional restrictions on size of pot, size of mesh, and minimum length of eel (Maine State laws, 12 MSRA Sections 7053, 7153). Although harvest information was requested, they were not required to report harvest effort, total catch, or locations fished. Resource managers need these data as well as baseline data on population densities to assess the relative effects of harvest pressure and environmental changes.

Some data on densities and relative abundance of American eels are available. Smith and Saunders (1955) report densities of eels ranging from 12 to 529 eels/ha in lakes in eastern Canada. They also found a correlation between distance from the ocean and density of eels. Recent work on American eels in Maine rivers indicates a smaller range in densities, 1.8 to 35.4 eels/ha (K. Oliveira, University of Maine, personal communication). No significant correlation was found between distance from the ocean and eel density; however, for all but one river, upstream sections had lower densities of eels. Ford and Mercer (1986) estimated 875 eels/ha in a salt marsh. Researchers of European eels (*Anguilla anguilla*) report similar densities of eels (6 to 126 eels/ha) and decreasing density with increasing distance from the ocean (Tesch 1977; Vøllestad and Jonsson 1988; Lobon-Cervia et al. 1990; Mann and Blackburn 1991; Barak and Mason 1992).

Although American eels have been studied for decades, there are no data on efficiency of harvest effort or recovery of harvested populations of eels. Studies on European eel populations where eels were removed for scientific purposes suggest a recovery period of more than two years (Lobon-Cervia et al. 1990; Mann and Blackburn 1991). Conversely, Mann and Blackburn (1991) found a decrease of less than 50% of original eel densities after five years of removing eels from their study location. In this study, we examined population densities, harvest efficiency, and recovery of harvested populations of American eels in inland waters in Maine.

Methods

Populations of American eels were estimated in five lakes and one river located in central Maine (Table 1). Hermon Pond, Jacob Buck Pond, and Long Pond were sampled between 5 May and 20 October 1998. Etna Pond and Wight Pond were fished between 23 April and 3 October 1999. The eel population in the Kennebec River was commercially harvested by a local eel fisher between 19 July and 15 September 1999. Four of the five lakes are considered shallow, warmwater systems. Jacob Buck Pond is a deeper, more oligotrophic lake. Surface areas of the study locations ranged from 54 to 184 ha, and distances from the ocean were between 2.5 and 22 km.

American eels were captured in commercial eel pots (275 mm diameter, 750 mm long, 12.5 mm mesh). Pots from the lakes were retrieved, emptied and re-baited with earthworms or fish every two to ten days depending on capture rates. Eels from the lakes were measured to the nearest 5 mm. In 1998, eels were removed and relocated outside of the watershed from Jacob Buck Pond and Long Pond to simulate a commercial fishery. Eels collected from Hermon, Etna, and Wight Ponds were marked and released some distance from their location of capture. The distal end of the right pectoral fin was clipped to mark eels. Unmarked American eels captured on subsequent sampling trips were also marked and released. Other vertebrate and macroinvertebrate organisms captured in the pots were identified, counted, and released. In 1999, a subset of the pots was fitted with smaller mesh (1.67 mm) and placed in four lakes in an attempt to capture any smaller eels that might escape from the commercial-sized pots. Small-meshed pots were set in: Etna Pond, Jacob Buck Pond, Long Pond, and Wight Pond.

Large numbers of eels were captured from the Kennebec River, so a random subsample of 50 eels was measured and the total weight of the catch was recorded for each date. The mean weight of eels per date was estimated from mean length that day using a length-weight regression (K. Oliveira, personal communication). Number of eels per day was estimated by dividing the estimated mean weight of eels per day into kilograms of eels captured.

Population sizes were estimated using two formulas depending on the sampling method. We estimated population sizes and confidence intervals for mark-recapture data using the modified Schnabel formula (Ricker 1975). We used the Delury formula to estimate eel populations from removal data (Ricker 1975). Confidence limits for the Delury method were estimated by bootstrapping (100 replicates sampled with replacement). The population at the Kennebec River site was estimated using the Delury method and the estimated number of eels captured per day. If the estimate of the lower limit for the population was below the total number of eels captured, the lower confidence interval was adjusted to that number.

Densities of eels (eels/ha) were estimated by dividing estimates of the original populations by the area of each location. Area for the river section was estimated from mean widths along the length of river fished. These data were obtained from USGS topographic maps. We estimated biomass of eels (kg/ha) using mean eel lengths at each location and a length-weight regression for eels in Maine (K. Oliveira, personal communication). We then multiplied the density of eels per hectare by the estimated weight of the average eel for each location.

Harvest efficiency was estimated by dividing the number of individual eels captured by the point estimate of the population. To estimate recovery rates of harvested eel populations, Jacob Buck Pond and Long Pond were resampled in 1999. Recovery estimates were obtained by comparing mean catch per unit effort (CPUE) and total number of eels captured during and one year after the simulated harvests. To look at the efficiency of the small-meshed and commercial eel pots, we calculated CPUE based on all of the eels captured by location. We excluded recaptured individuals when calculating CPUE for comparison among locations and between years.

Population characteristics were also examined. Differences in mean lengths among locations and among months captured were tested using one-factor ANOVA and Tukey's multiple comparison procedure. Significance values were set at $p = 0.05$. The proportion of females harvested was also examined. All eels over 400 mm were assumed to be females (K. Oliveira, personal communication), those less than 400 mm were of undetermined sex.

Results

Population and density estimates

Estimated densities of eels varied among lakes, ranging from 2.1 eels/ha (0.52 kg/ha) at Etna Pond to 8.4 eels/ha at Hermon Pond (1.86 kg/ha) (Table 2). The Kennebec River section had the highest estimated density of eels (32 eels/ha, 8.9 kg/ha). There was a general trend for larger water bodies to have both higher population estimates and higher densities of eels.

Harvest efficiency

Commercial eel pots harvested large portions of the eel populations (Table 3). Harvest efficiencies ranged from 36 to 95% of the point estimate of the populations. Locations with higher densities of eels had higher harvest efficiencies. The Kennebec River had the highest CPUE (0.316 eels pot^{-1} day^{-1}) while Long Pond had the lowest (0.045 eels pot^{-1} day^{-1}) (Table 3). Only Hermon and Jacob Buck Ponds had CPUE values close to the commercially harvested population in the Kennebec River.

Only four eels were captured in small-meshed pots, all in Wight Pond. CPUE was lower for the small-meshed pots (0.015 eels pot^{-1} day^{-1}, based on total catch) than for commercial eel pots (0.076 eels pot^{-1} day^{-1}, based on total catch) in Wight Pond, indicating that the small-meshed pots were less efficient. Therefore, small-meshed pots were excluded from subsequent calculations of CPUE.

Recovery rates

American eel populations were greatly reduced one year post harvest. Between 1998 and 1999, CPUE dropped by over ten-fold at both locations. One year post-harvest only 7 eels were captured in Long Pond (CPUE = 0.004 nos pot^{-1} day^{-1}) and 16 eels were captured in Jacob Buck Pond (CPUE = 0.013 nos pot^{-1} day^{-1}). Commercial harvest of eel populations in these lakes was successful at capturing most of the eels available in the first year of fishing. Low catch rates and limited numbers of eels captured precluded estimating population sizes during the second year.

Characteristics of harvested eels

Mean length of eels varied between the Kennebec River (mean = 540 mm) and Jacob Buck Pond (mean = 448 mm) populations (ANOVA, $p<0.05$, df = 5, 2667) (Table 4). Size ranges were similar among the other locations. Minimum lengths of eels captured varied from 270 to 305 mm. Maximum lengths captured were more variable, ranging from 730 to 990 mm.

An estimated 84% of eels measured was classified as females, the other 16% were of undetermined sex (Table 4). Females dominated the catches at all locations, comprising 67 to 89% of the population vulnerable to harvest. The highest estimated proportion of females occurred in the Kennebec River harvest, the only location that was commercially fished.

Mean length of eels captured differed by month at three locations over the study period (Table 5). Small numbers of eels prevented examining mean length by month at Long Pond, so it was excluded from this analysis. At Hermon Pond and Jacob Buck Pond, mean length of captured eels decreased over the first three months of sampling. On the other hand, mean length of eels increased between August and September on the Kennebec River (ANOVA, $p<0.001$). Mean length of eels at Etna and Wight Ponds did not change over time.

Discussion

Several factors may have biased our population estimates. The mesh size on the commercial pots allowed small eels to escape; therefore, estimates were limited to eels larger than 270 mm. Additionally, population estimates based on mark-recapture data have been shown to be biased, particularly when the same method is used to capture fish for marking and recapturing (Beukema and Vos 1974). Passive gear (fyke nets) tend to underestimate actual populations while active gear (seines and angling) tend to overestimate actual populations. These two factors would lead to underestimates of the eel populations and overestimates of the over-all harvest efficiency. Because we used commercial pots, we believe our population estimates are indicative of populations vulnerable to harvesting, and that harvest efficiencies are accurate for Maine eel fisheries.

Although our density estimates were within ranges reported by other researchers, they tended to be lower than most of the other locations studied (Smith and Saunders 1955; Ford and Mercer 1986). Distance from the ocean may explain this, as three of our study locations were ten or more kilometers away. Two of those locations (Hermon Pond, Kennebec River) had high densities of eels compared to the other lakes in our study. Hermon Pond was still low compared to other estimates of American eel density in lakes (Smith and Saunders 1955). The density of American eels at Kennebec River was closer to the other estimates (K. Oliveira, personal communication), but was lower than the highest densities reported. The eel population from the Kennebec River probably included some migrating silver eels. This would explain the increase in mean length over time. Population estimates are inherently biased whenever systems are not closed to immigration and emigration (Ricker 1975). We limited our sampling time at the study locations to minimize these confounding effects.

The high proportion of females is also consistent with other research on American (Helfman et al. 1987; Jessop 1987) and European eels (Vøllestad and Jonsson 1988). Vøllestad and Jonsson found higher proportions of larger, female eels as distance from the ocean increased, and recent work on American eels suggests a similar trend (K. Oliveira, personal communication). While mean length of eels did not differ significantly among most locations, mean length and proportion of females did tend to increase as