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Maritimes Region

Assessment of the Maritimes Region American Eel and Elver Fisheries

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Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The Maritimes Region eel and elver fisheries, last assessed in 1996, were re-assessed in order to: provide advice to management concerning the present status of the region's American Eel population; evaluate current sources and potential impacts of human-induced mortality on American Eel productivity; and to develop mortality (F) reference levels that correspond to Spawning biomass Per Recruit (SPR) for $SPR_{30\%}$ and $SPR_{50\%}$. Assessment of the eel fishery was limited by the availability of data. Landings and the reported locations of landings indicate that the fishery is currently low effort and landings are therefore considered to only have a moderate impact on eel productivity. The elver fishery, although geographically extensive, is relatively moderate in size on the basis of the proportion of eel habitat that is subject to elver fishing. Exploitation rates where elver fishing occurs are generally moderate, with the exception of fisheries at the mouths of river drainages of approximately 250 km^2 or less. The extent of overlap, relative to total habitat available to American Eels, between eel and elver fisheries, has been moderate (6–8%) in recent years. However, extent of overlap is sensitive to the participation rate and choice of fishing locations by American Eel fishers. Mortality reference points were proposed for the eel and elver fisheries and for silver eel escapement past hydroelectric dams. The elver fishery was assessed relative to F = 1.2 and F = 0.69, which correspond to $SPR_{30\%}$ and $SPR_{50\%}$, respectively, using habitat-based elver production indices derived from observed and modelled elver recruitment, and fishery escapement estimates for East River-Chester. Overall, exploitation of elvers lies below $SPR_{30\%}$ but indications of overexploitation are apparent among river drainages less than 250 km^2. Collectively, these represent about 6% of the total habitat available to eels in the Maritimes Region, approximately 20% of the total area fished for elvers, and around 70% to 73% of the 110 river drainages that are authorized for elver fishing. The long-term-median estimate of East River-Chester elver recruitment is recommended as the primary indicator of American Eel productivity, until such time as either fishery-dependent or fishery-independent indicators of American Eel status become available.

INTRODUCTION

The American Eel, *Anguilla rostrata*, is a widely distributed fish that occurs from northern South America to Greenland and Iceland. They are panmictic (all are members of a single population), generally catadromous (spawn at sea and spend a portion of their lives in freshwater) and semelparous (a single reproductive episode followed by death). Spawning occurs in the Sargasso Sea, well to the south of Canadian territorial waters. Juveniles recruit as glass eels (elvers) to Canadian continental waters in the year following the year of their hatch. In Canada, the American Eel can be found in nearly all the accessible fresh, brackish and protected coastal waters, from the Canada-United States of America border in the south to Lake Melville, Labrador, in the north, including the Laurentian Basin of the provinces of Ontario and Québec and the island of Newfoundland. They have historically been fished by Indigenous Peoples for food, social, and ceremonial purposes, and these fisheries remain culturally important. American Eels have also supported commercial and recreational fisheries throughout much of their Canadian range. The Maritimes Region (Figure 1) commercial fishery is the only eel fishery in Canada that results in significant removals of eels as recruits (glass eels or elvers), as juveniles (yellow eel), and as adults (silver). All removals by fisheries occur pre-spawning.

Elvers are defined in regulations as eels less than 10 cm (4”) in total length and, in the Maritimes Region, they are managed as a distinct fishery. An Integrated Fisheries Management Plan (IFMP) was developed for the Maritimes Region elver fishery in 1998 (DFO 1998) and updated in 2018 (DFO 2018) to help guide regional fisheries management decisions. The updated IFMP was developed following the DFO framework for an ecosystem approach to integrated management (DFO 2007). The framework defines three conservation objectives that require consideration during IFM Planning. These objectives are:

1. Productivity: Do not cause unacceptable reduction in productivity so that components can play their role in the functioning of the ecosystem.
2. Biodiversity: Do not cause unacceptable reduction in biodiversity in order to preserve the structure and natural resilience of the ecosystem.
3. Habitat: Do not cause unacceptable modification to habitat in order to safeguard both physical and chemical properties of the ecosystem.

The fisheries for yellow eel and silver eel—generally referred to as ‘large eels’ or simply ‘eels’— are managed collectively. An IFMP has not been developed for the eel fishery.

The status of the Maritimes Region eel and elver fisheries were last assessed in 1996 (Jessop 1996a,b). More recently, indices of general status were compiled in support of a national pre-COSEWIC (Committee on the Status of Endangered Wildlife in Canada) review (Bradford 2013), a Recovery Potential Assessment (RPA) of the American Eel (DFO 2014), and to help measure progress towards reducing human-induced mortality by 50% (DFO 2010). The 2012 COSEWIC assessment designated the American Eel as threatened (COSEWIC 2012). They are currently under consideration for listing under the *Species at Risk Act*.

In support of the management of eel and elver fisheries for American Eel, DFO Maritimes Fisheries Management has asked DFO Science for an assessment of resource status and the consequences of various harvest levels and strategies. DFO Science determined that a framework review of the assessment information and approach was required to establish the scientific basis for the provision of advice to management. The framework meeting, completed in October 2016 (DFO 2017), evaluated the usefulness of existing data sets as a means to assess the impacts of the principle sources of human-induced mortality (directed fisheries for large eel and elvers, and hydroelectric generating facilities [DFO 2014]) on American Eel status, and for use in the development of F-based reference points. The current distribution of the invasive swimbladder parasite (*Anguillicoloides crassus*), a relatively recent arrival into Maritimes Region waters (Aieta and Oliveira 2009, Campbell et al. 2013), was also evaluated. The potential loss of eel productivity that could result from infection with the parasite is not fully understood at present. A negative impact is anticipated (COSEWIC 2012, DFO 2014).

The purpose of this assessment is to develop advice for management using the framework approach, which in broad terms aims to evaluate the effects of human-induced mortality on eel productivity and biodiversity at both the regional and local (e.g., individual watershed) scales.

The specific assessment objectives are to answer the following questions:

1. What trends in stock status and exploitation are seen in the fishery-dependent and fishery-independent time series used to inform status of elver recruitment and fisheries in the Maritimes Region?
2. What has been the annual extent of spatial overlap of the large eel and elver fisheries, since 2015?
3. Based on an SPR analysis, what are the recommended reference points for large eels to allow for escapement from fisheries and hydroelectric facilities, and it's current mortality within those levels?
4. What are the recommended F-based reference points for elver fisheries in the Maritimes Region? What is the status of current exploitation relative to the reference points?
5. What are the implications for existing management measures in the eel and elver fisheries if these reference points are adopted?
6. What is the schedule for future assessments of American Eel, and what will be included in the updates provided between assessments?

FISHERY MANAGEMENT

At least four pieces of federal legislation, in addition to the *Species at Risk Act*, have direct or indirect application to American Eel, namely, the *Fisheries Act*, the *Fishery (General) Regulations [F(G)R]*, the *Maritime Provinces Fishery Regulations (MPFR)*, and the *Aboriginal Communal Fishing Licences Regulations (ACFLR)*. The *Fisheries Act* is directed at protecting fish habitat, while its supporting regulations provide the tools to protect, conserve, and manage fisheries. Some of the most important regulatory provisions as applied to American Eel and elver fisheries are:

- Sections 36–38 of the MPFR, which establish gear restrictions, close times (fishing seasons), length restrictions, and quotas for recreational fishing;
- Section 6 of the F(G)R, which provides for the issuance of variation orders to change or close any fishing season, or size limit, set out in regulations; and

- Section 22 of the F(G)R which provides for the issuance of licence conditions.

Eel licences are valid for a county (Figure 2) and for both tidal and non-tidal waters. Elver licences are valid only for the coastal drainages that are named in the conditions of licence that are specific to each licence.

LARGE EELS (YELLOW AND SILVER)

There are no management targets or catch quotas for commercial, commercial communal, recreational, or Indigenous Food Social Ceremonial (FSC) eel fisheries in the Maritimes Region. However, both regulations and licensing policies have changed with time in response to conservation concerns. Since May 1993, no new commercial eel licences have been issued, and re-issuance of licences has been permitted only to registered licence holders in the preceding year. Recreational eel licences were frozen in 1997. Catches were subject to size and bag limits, and effort was restricted to use of a maximum of four pots. All remaining recreational licences are non-transferable, terminal.

Regulations presently in effect require:

- a licence to fish commercially (including commercial communal) or recreationally, except for angling or for spearing in tidal waters. Authorized fishing methods include angling, pots, traps (fyke nets and weirs), dip nets, and spears. Longlines and setlines are permitted in New Brunswick (NB). In inland waters there is a closed season for eel traps from November 1 to August 14, and for spears all year;
- a distance of 200 m be maintained from any fishing gear previously set;
- fishing gear not be left unattended for more than 72 hours;
- fishing gear be marked with the owner’s name and, where a vessel is used, with the vessel registration;
- eel traps to have a 90 cm opening to allow fish to escape, and fyke nets be rendered incapable of catching fish from sunrise to sunset in inland waters of Nova Scotia (NS);
- eels less than 35 cm Total Length (TL) be returned live to the wild;
- escape mechanisms with 1 inch (2.5 cm) by ½ inch (1.27 cm) openings for all gear;
- eels not be retained as a bycatch in any fishery (Section 33 of the F(G)R); and
- licence holders, as a condition of licence (beginning in 2014), to submit their logbooks to a Dockside Monitoring Company (DMC) for data entry. Because possession of the licence conditions is a requirement for commercial fishing activity to proceed, this measure essentially requires licence holders to report their fishing activities of the previous year (or to indicate that they did not fish) before engaging in commercial fishing during the current year. The returned logbooks provide information on daily catch and effort, by gear type, and by watershed.

ELVERS

Commercial elver fishing began as an Enterprise Allocation Fishery in 1996, following several years of experimental fishing beginning in 1989. Since 1998, the number of licences has been limited to nine. Each licence holder has authorized fishing areas (named rivers and streams), defined quantities and types of gear, and a defined maximum number of fishers that can be deployed to fish for an individual quota that is not transferable. Fishing areas were approved on the basis that no commercial fishing for large eels had occurred in any of the three previous years. This policy has remained in effect through the years, and it remains an important consideration when reviewing requests from licence holders to exchange an existing licenced river for a new fishing site. The effectiveness of the policy, as a means to discourage large eel and elver fishing in the same drainage, has not been evaluated.

Both the individual quotas and the circumstance in which the elver licence holders can fish above their quota have changed with time. Briefly, for the years 1998 to 2004, the individual quota was set at 1,333 kg wet-weight for 8 licence holders and 400 kg wet-weight for the other licence, yielding an overall Total Allowable Catch (TAC) of 11.06 mt wet-weight for the fishery. Each licence holder could apply for a quota increase of 30% once their individual quota had been reached, which increased the potential annual maximum catch to 1,733 kg for 8 licence holders and 520 kg wet-weight for the other licence.

In 2005, in response to conservation concerns expressed for the status of American Eel in Canada, individual quotas were reduced by 10% to 1,200 kg (n = 8) and 360 kg (n = 1) wet-weight, resulting in a reduction in the TAC to 9.96 mt wet-weight. The option to apply for a 30% increase in an individual quota was removed. However, licence holders can fish an additional 10% (120 kg and 36 kg) of quota if the fish are for conservation stocking in Canadian waters[1].

There are eight commercial licences and one commercial communal (First Nations) licence. Licence holders are not restricted to use of a single gear type while fishing a specific fishing location (i.e., dip netting can occur while set gear is installed and fishing). However, there are limits on the number of traps that can be set in a named fishing river, usually no more than 2 or 3, depending upon the licence. Minimum distances between gear are defined. There is no limit on the number of persons who can dip net for elvers on a given river at the same time, provided their numbers do not exceed the maximum stated on the licence. Use of wings when dip netting is limited and subject to restrictions on the maximum width of the channel that can be blocked (one third and two thirds in tidal and non-tidal waters respectively). The overall gear amounts are summarized in Table 1.

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[1] Approximately 6,215,500 elvers acquired from commercial elver fishery licence holders were stocked into the Laurentian Basin between 2005 and 2010 (Stacey et al. 2014). The proportion of the stocked elvers that were fished as part of the 10% additional quota allocated for conservation stocking is not known but was probably low-modest.

DATA SOURCES AND DATA LIMITATIONS

MAPPING RESOURCES

River Drainage Locations and Area Estimates

American Eel are considered to be present in every drainage area with a direct connection to tidal waters within Maritimes Region, and they can be expected to be encountered in both lotic (running water) and lentic (lakes, ponds) freshwater habitats. The amount of each type of habitat contained within Maritimes Region river drainages has not been comprehensively quantified. Estimation of the proportions of freshwater rearing-habitat, impacted by human activities that result in eel mortality, is, therefore, limited to the use of the total surface area of individual river drainages as an index of available habitat.

Information concerning the surface areas of individual river drainages was extracted, when available, from the digital New Brunswick (NB) Hydrographic Network (NB Department of the Environment, Fredericton, NB), and the Nova Scotia (NS) Secondary Watersheds (NS Department of the Environment, Halifax, NS) mapping series. However, both eels and elvers are fished in numerous, small, river drainages having a direct connection to tidal waters that are not resolved within the existing river drainage polygon divisions of the digital map series. Area estimates for these were acquired by hand drawing polygons along the heights of land separating adjacent watersheds.

Gazetted names for all drainages were acquired from the New Brunswick Geographic Information Corporation (1993) and Nova Scotia Geomatics Centre (2001).

The total drainage area of the Maritimes (Scotia-Fundy) Region boundary zone has been estimated to be 118,846 km^2 (Cairns et al. 2014) and is shown in Figure 3, of which 55,111 km^2 (46.4%) is contained within the Saint John River system. Not all wetted habitat contained within the Saint John River is available to American Eels. For example, Grand Falls (23 m in height), located at River Kilometer (RK) 360, is a natural barrier to upstream migration for a variety of fish species (Kidd et al. 2011). The absence of verifiable records of American Eel occurrences within the 8,114 km^2 of river drainage above Grand Falls indicates that this portion of the Saint John River may not be accessible to American Eels via natural colonization. The historical extent of occurrence of American Eels in the Maritimes Region is, therefore, estimated at 110,732 km^2.

The Mactaquac Dam (approximately 40 m in height) at RK 140 (Kidd el al. 2011) is considered to be a man-made barrier to upstream-migrating American Eels. Eels have only rarely been captured during DFO-Science electrofishing surveys of tributaries lying above the dam (Table 2b), whereas they are common in electrofishing surveys conducted in tributaries lying below the dam (Table 2ai and Table 2aii). The few eels that have been detected above the Mactaquac Dam may be the result of the incidental transport-release of eels that were captured in collection galleries operated at the base of the dam to facilitate the trapping and transport of Atlantic Salmon (*Salmo salar*) and alosine fishes. Elvers have been observed at the base of the dam in past years (Groom 1975), and juvenile (yellow) eels are present in observable numbers in the vicinity of the collection galleries during the summer months (R.G. Bradford, DFO; personal observation). The river drainage area for the portion of the Saint John River lying between Grand Falls and Mactaquac Dam has been estimated to be 17,014 km^2 (Kidd et al.

2011). The drainage area of the Saint John River lying below Mactaquac Dam is presently the only portion of the river that is considered to be accessible to American Eel via natural colonization. This area has been estimated to be 29,983 km^2 (Kidd et al. 2011). The current extent of occurrence of American Eel within the Maritimes Region is, therefore, estimated to be 93,718 km (Figure 4).

FISHING LOCATIONS

Elver Fishing

Elvers are defined in regulations as an eel of less than 10 cm TL. Elver fishing occurs near or at the head of tide within a specific and limited number of river drainages that are specified in licence conditions that are renewed annually. Rivers have been made available for elver fishing on the basis that fishing for large eels has not occurred within the river during the past 3 years. Many of the 65 rivers where elver fishing was authorized at the onset of commercial fishing in 1996 remain active and are fished annually whenever market conditions justify the effort. However, other rivers that were assessed for elver fishery potential during the early years of the fishery were abandoned or exchanged for another river. Fishing locations and the number of rivers individual licences have been authorized to fish have changed with time, either through addition of additional rivers, or by exchanging one river for another, or via exchanges of rivers among licence holders. There are presently 110 authorized elver fishing locations, not all of which are fished annually.

Documentation of elver fishing activities is extensive and includes the reporting of catch (as kg wet-weight), effort, gear type, and the amount of gear used during each fishing excursion. The logbooks maintained by the licence holders are submitted annually to the DFO and represent a source of information for identifying the locations of elver fishing activity.

Eel Fishing

Records for eel fishing activities prior to 2008 do not provide detailed information concerning fishing locations, or catch per licence, or catch per unit of effort, or catch by gear type for the Maritimes Region fishery (Bradford 2013). Unlike the elver fishery, where licence holders are authorized to fish only within specific river drainages, eel licences are valid for a county lying within the New Brunswick and Nova Scotia portions of Maritimes Region. The river systems where fishing occurred within the county were not reported. Attempts initiated in 2000 to acquire a more comprehensive portrayal of the spatial character of this fishery by providing space on logbooks to report locations were not successful. Compliance with the request for additional detail was low, and the logbook return rate was low. Logbooks were not distributed for the 2008 fishing season.

A re-designed logbook that allowed for the recording of daily fishing activity by location, gear type, number of gears and soak time was available for the 2009 fishing season. Compliance with the condition of licence that required return of the logbook to DFO prior to the next fishing season remained low.

Since the beginning of the 2014 fishing year, licence holders have not been issued their conditions of licence until they have demonstrated that their logbooks for the previous year had been submitted to a DMC for data entry. Possession of the licence conditions is a requirement before commercial fishing activity can proceed. Many licence holders do not submit their logbooks to a DMC until shortly before they plan to fish, which can result in a lag of about one year in the completion of logbook reporting. This limits current use of logbook data for identification of large eel fishing locations to the 2015 and 2016 fishing seasons.

The geographic extent of FSC fishing activity for eels is not well known and, therefore, the extent of overlap between FSC and commercial fisheries is not known. It is assumed that FSC fisheries can occur in all coastal/inland waters contained within Maritimes Region.

HYDROELECTRIC UTILITIES

Chaput et al. (2014) reported there were at least 17 hydro systems, 54 generators, and as many as 155 dams in Nova Scotia lakes and rivers that are used to generate electricity. One hydro system may contain several generators and several dams to generate electricity. An additional 8 hydro systems exist on New Brunswick rivers draining to the Bay of Fundy. These are distributed among three rivers, the St. Croix River, the Magaguadavic River, and the Saint John River.

Published estimates of downstream bypass efficiency and/or turbine mortality for hydro systems located within the region are presently limited to those reported by Carr and Whoriskey (2008) for a hydroelectric generating facility installed in the Magaguadavic River. They reported use of a bypass facility by 6 (24%) of 25 acoustically tagged silver eels and total mortality of the 19 eels that passed through the turbines, yielding an overall mortality rate of 76% for the sample population.

Estimation of the watershed area lying upstream of specific hydroelectric generating facilities, the type and number of turbines installed, and the availability of upstream and downstream bypass facilities continue to be developed. Total drainage area will, therefore, be used in this initial description of area under hydroelectric generating influence. Drainage area estimates were either extracted from existing data bases when possible or estimated from hand-drawn polygons.

SWIM BLADDER PARASITE

Campbell et al. (2013) contains the details of the only attempt to acquire information concerning the spatial distribution of the swim bladder parasite in Maritimes Region. Their assessment was based upon samples of eel bycaught in region-wide juvenile salmonids electrofishing surveys of riverine habitat conducted during 2008 and 2009. The authors also summarized the waterbodies identified by other investigators where presence of the parasite had been detected. Updates beyond these records are limited to the reporting of information from collaborative DFO-Industry projects that involve large eel sampling in Oakland Lake Stream and the East River-Chester, Lunenburg County, Nova Scotia.

EEL LIFE-HISTORY DATA TO SUPPORT SPAWNER PER RECRUIT ANALYSIS

The proposed approach to define whether anthropogenic driven mortalities on eels are within acceptable levels is the Spawning biomass Per Recruit (SPR) model, as described by Mace and Sissenswine (1993). This model was initially applied by the International Council for the Exploration of the Sea (ICES) to the American Eel (ICES 2001). Chaput and Cairns (2011) recommended that the fishing mortality rate that results in 30% SPR would be used as the limit mortality reference point and 50% SPR would be the value for rebuilding and long-term management, as proposed by ICES (2001).

SPR models are age structured and use the life-history parameters of a species to calculate the ratio of spawner potential produced under a scenario of anthropogenic mortality, relative to a scenario where anthropogenic mortality is zero. The models do not require estimates of recruitment, and, as presented, assume there is no density dependence, which may not be correct. The analysis of Bevacqua et al. (2010) indicated that natural mortality may vary with density for the European Eel (*Anguilla anguilla*), for example. In evaluating the effects of human-induced mortality, the same set of "average" life-history parameters is used and the spawning biomass that remains after human-induced impacts is compared to the spawning biomass expected in the absence of the human-induced mortalities (% SPR). SPR analysis makes no assumption about the recruitment that is obtained from a spawning escapement (Chaput and Cairns 2011).

The life-history parameters (Figure 5 and Figure 6) applied to SPR analysis of the Maritimes Region eels were:

- Total Weight (g) = 0.0007006*Length (mm)$^{3.2332}$ (Cairns et al. 2008)
- Fecundity = 18.2*Length(mm)$^{2.9642}$ (Barbin and McCleave 1997 for freshwater resident eels at 45°N Latitude)
- Mortality at sea (M_{atSea}) was drawn from N(0.1,0.01) (Chaput and Cairns 2011).
- Natural mortality at-age was estimated using the method of Bevacqua et al. (2010), assuming a mean temperature of 8 °C. Vulnerability to human-induced mortality considered two scenarios: 1) only elvers (recruits) are selected at river age 0+ years; and 2) knife-edge selectivity of eels above legal-minimum-size of 35 cm TL.

FISHERIES DEPENDENT INDICES

Large Eel Fishery Potential and Catch and Effort

The limitations discussed above concerning the use of eel-fishery logbook returns as a source of information concerning the locations of fishing activity, extend to catch and effort data. Briefly, records of eel catch and effort for the years prior to 2008 are poor. They are considered to be only a record of reported annual landings rather than an indicator of regional status (Bradford 2013). Efforts to improve both the quality of the data received, and the level of compliance with the requirement to return logbooks, were not overly successful in the years since 2008. Stricter conditions on eel fishing since 2015, including a requirement that licence holders demonstrate, before receiving authorization to fish, that they have submitted their records of eel fishing activity from the previous season to a DMC, has resulted in more detailed catch records but only for the 2015 and 2016 seasons. Evaluation of the annual fishing activities relative to the number of licences issued, the type, and the amount of gear that could potentially be fished, and participation in the fishing, is limited to these years.

The reported landings by province for the years 1950 to 2016 are summarized in Figure 7. There is no systematic gathering of information for landings resulting from FSC fishing activities.

Licencing information is available for the commercial, commercial communal (First Nations), and recreational sectors of the fishery.

Elver Fishery Potential and Catch and Effort

Fishing records are available for each year, beginning in 1996 to present, except for 2008 when logbooks were not distributed to licence holders. In raw form, the records contain numerous inaccuracies that can be attributed either to one of the following: data entry errors, or inconsistent reporting among years of catch in terms of wet versus dry (wet-weight less 25%), or non-standard and inconsistent naming of fishing locations. Prior to 2016, daily catch and effort for individual fishing sites were not consistently separated by gear type, particularly between dip netting and fyke netting activities. The transition in recent years to the capture of data in an electronic format, via submission of logbooks by the licence holders to DMCs, has presented challenges with respect to the documentation of accurate catch weights by gear type.

Many of the substantive data quality issues have been resolved for existing records and have been addressed to enable better data capture moving forward. However, assessment of elver catch and effort for individual licence holders, and for the entire fishery, remains limited to coarse evaluations of catch and effort (i.e., total annual catch and total hours fished with no sub-division by gear type). Trends in elver fishery status are accordingly limited to the reporting of landings per year for the current assessment.

A sub-set of the information has, however, been extensively reviewed and edited with the assistance of the licence holder whose licence authorizes commercial fishing on the East River-Chester site, the principle elver-run monitoring site in the region. These records allow for assessment of annual fishing success and exploitation, relative to annual estimates of elver recruitment to the river.

Fisheries Not Directed Toward Either Eels or Elvers

There are no commercial, or commercial communal, or recreational fisheries with significant bycatches of either eels or elvers.

FISHERIES INDEPENDENT INDICES

Regional Electrofishing Surveys

Freshwater fish communities are monitored in numerous Nova Scotia and New Brunswick rivers, using either annual or periodic electrofishing surveys. The main goal of these surveys is to estimate juvenile Atlantic Salmon abundance and trends (e.g., Bowlby et al. 2013). Although these surveys were not specifically designed for American Eel, they represent the only regional data source available to develop a fishery-independent index of abundance of American Eel in fresh water. Accordingly, the average annual bycatch of American Eels in a sub-set of the surveyed rivers; therefore, the LaHave and St. Mary’s rivers (NS), and Nashwaak River (NB), have been reported previously (Cairns et al. 2014) as status indices. These series, last updated to 2015, portray a mutually consistent pattern of decline from their series highs and suggest that American Eel densities are low, relative to the mid nineteen nineties. (Table 3; Figure 8).

An extensive analysis of the annual and periodic surveys conducted in NS rivers (summarized in DFO 2017, documentation in Bowlby 2018) affirmed the patterns of decline from series highs, perhaps by as much as 89% over 10 years (DFO 2017). The analysis also indicated that incorporation of site-specific catch data are required in order for estimates of year-over-year change in eel abundance to be statistically robust.

Analysis of the full electrofishing data set from NS and NB rivers has been deferred until after completion of the region-wide electrofishing survey that is planned for 2019.

Silver Eel Abundance Indices

There are no published estimates of silver eel escapement for any of the major rivers located in the Maritimes Region. Annual monitoring of the run-size of silver eels from Oakland Lake Stream and Eel Lake Pond, two small coastal drainages along Atlantic Coastal Nova Scotia (Table 4), began in 2011 and 2014, respectively. Seven years and two years of count data are available for Oakland Lake Stream and Eel Pond Brook, respectively. Neither brook is fished commercially for elvers. Commercial fishing for large eels is not known to have occurred in either location in recent years.

Elver and Juvenile Eel Abundance Indices

Estimates of total elver run-size and elver escapement past directed fisheries, are limited to East River-Chester (Figure 9), a 134 km^2 watershed in southwestern Nova Scotia. These estimates are an outcome of industry-supported monitoring of the timing, abundance, and biological traits of the annual runs from 1996 to 2002, and 2008 to 2018. The combined elver count and harvest data has frequently been used as an indicator of elver status for the region (Bradford 2013, Cairns et al. 2008, Cairns et al. 2014, COSEWIC 2006, COSEWIC 2012, DFO 2014). Details of the elver-monitoring protocols are provided in Appendix 1.

For this data, collection traps are installed along the bank of the river below a rock sill during spring, when river and weather conditions allow. The sill impedes the upstream migration of the elvers. River water, supplied via gravity feed to the traps, acts as attraction flow, and leads elvers into holding boxes. The boxes are checked once or twice per day, depending upon the intensity of the run. The resulting abundance data (number of elvers and wet-weight of trap catches), in combination with daily catch and effort data for the commercial fishery that occurs in tidal waters downstream of the monitoring site (Figure 9), are used to generate estimates of total run-size, escapement past the fishery, and exploitation by fishing.

Elver lengths and elver weights can decline significantly over the duration of annual runs. These changes present a challenge to estimating run-size in terms of number of elvers when daily catches are large and hand counts become impractical. Conversion factors, based upon calibrations of the number of elvers per unit volume, are required to relate elver numbers to catch volume. The number of calibration events conducted during the runs has varied among years, thus lending uncertainty to run-size estimates expressed as number of elvers. A re-sampling routine was applied to relate elver length and elver weight information to volume-based estimates of daily trap catches to number of elvers (Appendix 1) and compared to those generated using only the available calibration data for a given year. The results showed that estimates generated following the conventional method of converting daily catch volumes to elver numbers were more variable than the estimates generated using information on either elver lengths or elver weights. The time series of elver counts generated using elver lengths is the most complete and has, therefore, been adopted as the series that represents run size (n) estimates generated prior to 2016. The catch-volume-based approach was replaced with a catch-weight-based approach in 2016, to better relate elver escapement to commercial catch.

Juvenile eels that are predominantly of river age 1+ years are also captured in the traps. Records are not available for all years that monitoring occurred, but those that are available represent a complete count for most of the years of sampling. These count data have not been previously assessed in the context of a potential indicator of population status or as an indicator of the potential effects of fishing and inter-annual-variability in elver total-run-size or escapement on local-population status.

Estimates of annual elver run-size (number of elvers only) are available for East River-Sheet Harbour for the years 1990 to 1999. Descriptions of the methods used to collect and count elvers are available in Jessop (2003); they are generally similar to those described above for the East River-Chester index for the years 1996 to 2001. These data were reported previously by Cairns et al. (2014).

Commercial elver fishing has occurred on East River-Chester in every year of elver monitoring, except for 2000. The detailed records of daily catch and effort, in combination with the counts obtained from the daily monitoring that occurs just upstream, have been shown previously to be useful to understanding the effects of fishing on elver recruitment to the river (Jessop 1998a, 2000a,b).

Data for the regional commercial elver fishery are presently limited to reported total catch per licence. However, a sub-set of the data collected, for rivers lying within the counties of Lunenburg and Halifax, Nova Scotia (Figure 1), is available to support exploration of the East River-Chester elver index as an indicator of status on a broader geographic scale.

DATA ANALYSES

FISHERY LICENCES, LANDINGS, LOCATIONS, AND EFFORT

Information contained on commercial eel licences was used to summarize licence availability and the total amount of gear by type (i.e., pots, traps, and weirs) that were available to fish for eels by province and by county for the years 2015 and 2016. Logbook returns were used to summarize the number of licences issued, the number of licences that were actively fished, the amounts of gear (by type), and reported catch sold-weights (kg) associated with active licences by province and county for each year. The summaries were compared, where possible, to the fishery averages (± 1 Standard Deviation) for the years 1993 to 2004 (extracted from Bradford 2013).

Information contained on both eel and elver licences and from logbook returns was used to align catch, and when possible, effort with river drainages (and in the case of the eel fishery, to county). All river names identified as fishing locations on licences and in logbook returns were assigned names as they appear in the Gazetteer of Canada for New Brunswick and Nova Scotia and/or on topographic maps. Drainage area (km^2) estimates, acquired as previously described, were used to relate fishing activity to area, and for rivers altered to generate hydroelectricity, and for the known areas of occurrence of the swim bladder parasite *A. crassus*.

Total areas for each activity (i.e., eel fisheries, elver fisheries, hydroelectricity generation, and parasite presence) were estimated when data allowed for summary, and organized as follows:

for the years up to 1969 which corresponds to completion of the Mactaquac Dam on the Saint John River; for the years 1970–2014; and individually for years 2015, 2016, and 2017.

The estimated cumulative area of impact for each activity was then reported as total drainage area (km^2) and the proportion of the total drainage area accessible to eels, either historically (pre-Mactaquac Dam) or at the present time. Drainage area estimates for two concurrent activities were estimated and similarly reported.

No reports of fishing activity under commercial communal licences for the 2015 and 2016 fishing years were received.

ELVER CATCH RELATIVE TO DRAINAGE AREA

A lognormal Generalized Linear Model (GLM) was applied to explore the relationship between the reported annual catch for a specific fishing location and the habitat area lying upstream of the fishing location (km^2) across all years of data. The scaled level of effort was included in the GLM as a weighting factor.

ELVER ABUNDANCE INDICES

The annual total counts of elvers on the East River-Chester trapped in the collection boxes (escapement) and reported landings from the commercial fishery (catch) that occurs a short distance downstream from the counting sites were used to estimate annual total run-size (kg and number of elvers) for the years 1996–2002 and 2008–2018.

Linear regression was applied to the East River-Chester (kg) and East River-Sheet Harbour (n, Years 1996 to 1999) data sets to acquire predicted runs sizes to East River-Chester for the years prior to 1996.

A model was developed to estimate East River-Chester elver escapement, given the fishery catch rates, with the objective of estimating total run-size for the years 2003–2007 when the elver index project was not operational but for which catch and effort information is available from the East River-Chester commercial elver fishery. The relationship was modelled as:

$$E \sim LN(\mu, \sigma)$$

$$\mu_i = \beta_0 + \beta_1 \cdot CPUE_i + \beta_2 \cdot CPUE_i \cdot Q_i$$

where, Escapement (*E)* was treated as a lognormal distribution possessing a linear relationship with CPUE. β_0 and β_1 were the slope and intercept, respectively. The licence holder for the elver fishery that includes East River-Chester fishes a number of rivers simultaneously. Equal effort is not exerted on all rivers where elver fishing is authorized either in a given year or among years. Therefore, the CPUEs for the rivers fished under the single licence were combined and evaluated for the potential to predict annual elver run strength. An indicator variable (0,1) representing whether the annual quota allocated to the licence holder was met (0) or not met (1) was included. Accompanying the indicator variable was an incremental parameter, β_2, which adjusted the slope when the quota was not met; that is when Quota = 1 the slope of the E~CPUE relationship became $\beta_2 + \beta_1$. This model was fitted in JAGS (Just another Gibbs Sampler, Plummer et al. 2013) for the East River-Chester fishery and for the licence holder's entire fishery with uninformative priors on the β as N(0,0.001) and on the σ as U(0,100). A burn-in of 1000 iterations and three chains of 15,000 MCMC iterations were sufficient to ensure full mixing. Chains were thinned by sampling 1 in 25 iterations to remove the autocorrelation with chains. Posterior distributions of all β and σ were updated from the priors during model runs (Figures 10 and 11). Several model formulations were explored, including a time-series model. Only the model described above is presented, as it possessed the lowest median prediction errors and lowest Deviance Information Criteria (DIC). There was a lack of temporal autocorrelation in escapement estimates.

ELVER TOTAL RUN SIZE/ESCAPEMENT AND SILVER EEL PRODUCTION ESTIMATES

Available observed estimates of elver total run-size (n and kg) and escapement (n and kg) were converted to elver abundance per 1 km^2 of receiving habitat by dividing each data series by the total watershed area estimate of 134 km^2 for the East River-Chester. Bootstrap re-sampling routines (n = 5,000) were applied to each data series to generate mean and median estimates of elver recruitment potential.

Complete annual counts of silver eel run-size from Oakland Lake Stream and Eel Pond Brook were considered to be too few to be meaningful in an analytical sense. Reporting was accordingly limited to run-size (n and kg) relative to drainage area and the amount of lake habitat (hectares) contained within the drainage system.

JUVENILE ABUNDANCE INDICES

The total annual catch of juveniles (n) in the East River-Chester elver traps was plotted versus year of catch, as well as versus elver total run-size (kg) and elver escapement (kg) for the previous year.

TEMPORAL TRENDS IN ELVER AND JUVENILE INDICES

Mann-Kendall (MK) trend analysis, a non-parametric test for monotonic trend in time-ordered data (Gilbert 1987), was applied to the elver and juvenile eel run size estimates. The null hypothesis is that the time series is independent and identically distributed (i.e., there is no significant trend across time).

SPAWNER BIOMASS PER RECRUIT IN EELS

Spawner biomass Per Recruit (SPR) analyses for American Eels were performed following the methods outlined in Gabriel et al (1989). Several modifications were required to describe American Eel life history. SPR was defined as:

$$SPR = \sum_{a} N_a^{Spawners} \cdot Fec_a$$

Where $N_a^{Spawers}$ represents numbers of spawning eels at age *a*, and Fec_a represents that fecundity-at-age. Fecundity-at-age was determined using the fecundity-at-length (*L*) model from Barbin and McCleave (1997) $F_L = 18.2L^{2.9642}$. The dynamics of N_a were described as

$$N_{a+1} = N_a e^{-(F_a + M_a)} - N_a^{mat} \; for \; a > 0, a < n$$

$$N_n = N_{n-1} \frac{e^{-(+M_a)}}{1 - e^{-(F_a + M_a)}} \; for \; a = n$$

$$N_a^{mat} = N_a \cdot Mat_a$$

$$N_n^{mat} = N_n$$

$$N_a^{Spawners} = N_a^{mat} - e^{-M_{atSea}}$$

Where F_a and M_a were fishing-at-age and natural mortality-at-age, respectively. Natural mortality-at-age was estimated using the relationship defined by Bevacqua et al (2010) with an assumed average annual temperature of 8 °C (Table 5). For each age (up to age *n*) a component of the population matures, N_a^{mat}, and is assumed to exit the freshwater environment. This component follows a different mortality schedule (M_{atSea} = 0.1) until reaching spawning grounds. The maturity-at-age (Mat_a) estimates were obtained from Chaput and Cairns (2011; Table 3), which were sampled from a beta distribution. The maturity- and numbers-at-age were combined to determine the resultant number of spawners.

Fishing mortality can occur at both the elver and older eel life stages in the Maritimes Region. Fishing mortalities ranging from 0–2 were explored to determine the impact on SPR for elvers and 0 to 0.5 for adult eels. F_{SPR30} and F_{SPR50} were identified as the fishing mortality levels that resulted in 30% and 50% of the unfished SPR (i.e., F = 0). SPR analyses were run for 25 ages with the assumption that all eels surviving to age 25 will mature and enter the spawning population. F_{SPR30} and F_{SPR50} were identified for elver and eel fisheries separately, as well, as if both fisheries were occurring on the same watershed.

Stochastic F_{SPR30} and F_{SPR50} (Figure 12) estimates were developed by incorporating variability in the life-history parameters, and performing 20,000 iterations, sampling across parameter distributions (Table 5). Although weight-at-age and fecundity-at-age are deterministic relationships, they are related to length, and will therefore vary between simulation runs.

RESULTS AND DISCUSSION

TRENDS IN STOCK STATUS AND EXPLOITATION

1. *What trends in stock status and exploitation are seen in the fishery-dependent and fishery-independent time series used to inform status of elver recruitment and fisheries in the Maritimes Region?*

FISHERIES DEPENDENT

Eels

There were 427 licences issued to fish eels during 2015 and 409 in 2016 (Table 6). Commercial licences accounted for the largest proportion of these (301 in 2015, 295 in 2016) followed by recreational (112 in 2015, 100 in 2016) and commercial communal (14 in both 2015 and 2016). The number of licences available to be fished in Nova Scotia inland and tidal waters exceeded those issued to New Brunswick by a factor of about 10 for all fishing sectors (Table 6).

More than 25,000 pieces of gear were authorized to fish for eels in both years, 90% of which were eel pots (Table 6), followed by fyke nets (traps, approximately 2,300) and a small number of weirs (26 in 2015, 27 in 2017). The Nova Scotia commercial and commercial communal fisheries are potentially larger than the New Brunswick fisheries by a factor of ten, both in terms of number of available licences and gear under licence (Table 6). All recreational fishing licences issued in both years were valid for Nova Scotia (Table 6).

Virtually all of the commercial licences available were issued in 2015 and 2016 (266 of the 268 available for Nova Scotia in 2016), shown in Table 7. NB fishers submitted 77% and 67% of their logbooks to a DMC for data entry in 2015 and 2016, respectively (Table 7). The reporting rate was lower, around 50%, in NS in both years (Table 7). Overall, the reporting rate was about 52% in both years (Table 7).

The number of commercial licences actively fished in NB was 23% (n = 7) in 2015 and 30% (n = 8) in 2016, whereas only about 11% of the licences issued in NS were active in either year (Table 7). Overall participation rates in the fishery were 12% in 2015 and 13% in 2016 (Table 8). The proportion of the total amount of gear available to be fished that was associated with actively fished licences was approximately 12% overall, reflecting overall participation rates in the fishery. However, fyke nets (traps) were an exception with approximately 19% of licensed fyke nets actively fished in 2015 and 37% in 2016 (Table 8).

Licences were issued for all NS counties and all but one NB county (Carlton) lying within Maritimes Region boundaries (Table 7). Yarmouth County exhibited the highest number of active licences (7 in 2015, 13 in 2016) followed by Shelburne County (5 in 2015, 4 in 2016). Four or fewer licences were active in any NB county, however, virtually all of the active fishing occurred in counties (shown in Table 7) that straddle the Saint John River (Queens, Saint John, Sunbury).

Overall, the amounts of gear available to be fished in 2015 and 2016 were lower than the amounts authorized under licence during the years 1993 to 2004 (Means and Standard Deviations [SD]: 31,752 ± 1,654 pots, 2,819 ± 177 fyke nets and 45 ± 5 weirs, Table 7). The number of active licences in 2015 (n = 36) and 2016 (n = 38) were lower than for the years 1993 to 2014 (mean ± SD 131 ± 27) as were the amounts of pots (2,095 in 2015 and 2,133 in 2016) and weirs (3 in both years). In comparison, Table 7 shows 1993–2004 gear calculated at mean ± SD: 4,254 ± 963 pots and 10 ± 5 weirs. The number of fyke nets (n = 788) on active licences in 2016 was above the average for 1993 to 2004 (mean ± SD 676 ± 255).

Total landings for the 2015 (36.1 mt) and 2016 (44.1 mt) eel fisheries were lower than those averaged for 1993 to 2004 (Mean ± SD: 164 ± 44 mt) by a factor of about 4 (Table 9b). Approximately 95% of the reported catch was sold in both years (Table 9a). The Saint John River fishery accounted for virtually all of the NB landings in both years and 36% and 53% of the total landings for the Maritimes Region fishery in 2015 and 2016, respectively (Table 9a).

Estimates of the area footprint of the fishery in the years prior to 2015 are difficult to acquire because fishing locations were not regularly reported with returned logbooks. The total drainage area fished for eel in 2015 and 2016 was 43,832 km^2 and 40,526 km^2, respectively, or about 47% and 43% percent of the Maritimes Region drainage area available to recruiting eels (Table 10). The area of the Saint John River lying below the Mactaquac Dam (29,983 km^2), that represents 32% of drainage area available to eels, therefore accounted for 68% in 2015 and 74% in 2016 of the area footprint of the eel fisheries.

The 2015 and 2016 Nova Scotia eel fisheries were, in contrast, more widely distributed with catches reported from 38 named river drainages, ten that were ≤ 25 km^2 in drainage area, and 20 ≤ 100 km^2 in area (data not shown).

Eels were fished within 5,253 km^2 (5.6 %) and 4,841 km^2 (5.25%) of the drainage area under hydroelectric development in 2015 and 2016, respectively (Table 11).

Available records indicate that as of 2016 the invasive swim bladder parasite *A. crassus* was present in 38,037 km^2 (40.6%) of available eel habitat (Table 10), 35,163 km^2 and 32,736 km^2 that were fished for eels in 2015 and 2016, respectively (Table 11).

Elvers

A complete description of the potential fishing effort available annually to exploit elvers since the development of the commercial fishery in 1996 is not available at the present time. Discussions with managers for the fishery indicate that the types of gear authorized for use (Table 1) have remained unchanged since 1996. Up to 2005, gear amounts, the type of gear authorized for use under individual licences, and the number of helpers (e.g., dip netters) probably changed as licence holders evaluated their requirements to effectively fish specific locations. Since 2005, gear types, the amount of gear, and the number of persons (dip netters) that are authorized to fish under a licence has remained unchanged (Table 1), with the possible exception of the licence issued to a First Nation under the *Aboriginal Communal Fishing Licences Regulations*.

The number of rivers where authorized elver fishing activities can take place had increased from 65 in 1996 to 111 by 2004. The number of rivers available for elver fishing has been frozen at 111 since 2005. The increase in rivers available for fishing, however, has not resulted in a large increase in the amount of receiving habitat exploited for the purpose of fishing elvers. The rivers fished during 1996 represented 24,178 km^2 (26%) of the drainage area lying within Maritimes Region, whereas the 111 drainages available for fishing in 2015, 2016, and 2017 represented 28,242 km^2 , 28,071 km^2, and 27,805 km^2, respectively, or about 30% of the Maritimes Region drainage area (Table 10).

Not all licensed rivers have been fished annually. The number of rivers with reported catches of elvers were 92, 86, and 83 for 2015, 2016, and 2017, respectively (Table 10). The associated areas of receiving habitat were 26,736 km^2 (28.5%), 25,679 km^2 (27.4%), and 25,794 km^2 (27.5%), as shown in Table 10. Between the years 1996 and 2014, 159 river drainages were either fished and/or evaluated for elver fishery potential. Collectively, these drainages represented 32,668 km^2 or about 35% (Table 10) of the 93,718 km^2 of drainage area available to recruiting elvers.

Elvers were fished within 10,388 km^2 of the drainage area under hydroelectric development (approximately 11% of available habitat) in 2015 and 2016 (Table 11). Eel and elver fisheries overlapped in 7,864 km^2 (8.4% of available habitat) and 5,238 km^2 (5.6% of available habitat) during 2015 and 2016, respectively (Table 11).

Available records indicated that elver fishing occurred in 4,771 km^2 (2015) and 4,610 km^2 (2016) of the 38,037 km^2 of habitat where the invasive swim bladder parasite *A. crassus* is known to be present (Table 11).

Landings from the elver fisheries exhibited a general increase with time (Table 12, Figure 13), following the transition in 1996 from the experimental (exploratory) fishery that occurred during 1989 to 1995. Total annual landings exhibited an overall increase with time, with the five biggest years occurring in the last six years of the time series which ends in 2017 (Table 12, Fig. 13). However, the annual TAC was not achieved in any fishing year.

Elver catches (kg wet-weight) fitted with a GLM, with scaled effort as a weighting factor, to the log-transformed drainage area (km^2) of fishing locations exhibited a positive increase with area (Figure 14).

DISCUSSION

Eels

The lower landings for the eel fishery during the most recent years for which data are available (2015 and 2016) appear to be the result, at least in part, of a substantively lower participation in the fisheries relative to the years 1993 to 2004. There were 38 or fewer active licences during both 2015 and 2016 versus an average of 131 during 1993–2004 (Tables 7 and 8). Inference concerning potential changes in catch rates with time are not possible given the absence of information concerning daily fishing activity for years prior to 2015.

The capacity to fish eels has declined since 1993–2004, when more than 30,000 gear units were under licence, to approximately 25,000 gear units in 2015–2016. The exchange of eel licences for green crab licences in recent years is responsible, in part, for the decline in both licences and amount of gear. Latent capacity to fish eels, however, should be considered to remain high in the inland and tidal waters of all counties lying within the Maritimes Region boundary. Non-active licences accounted for approximately 88% of eel pots that are baited to catch feeding yellow eels, around 60% of fyke nets that are used to fish both yellow and silver eels, and 88% of the weirs that intercept out-migrating silver eels. The potential, therefore, exists for fishing related eel mortality to be greater in future years should more of the current licence holders choose to fish. Eel fishing mortality could increase through higher participation in the fishery, both 1) within currently fished locations which represent around 47% (43,832 km^2) and approximately 43% (40,526 km^2) of available eel habitat in 2015 and 2016, and 2) through exploitation of eels in river drainages that are not presently fished.

Geographic extension of eel fishing activity could potentially result in higher cumulative human-induced mortality within river drainages where hydroelectric generation occurs and where fisheries for elvers occur. At present, eel fishery and hydroelectric generation interactions exist in about 5% of available habitat.

When considered in the context of the previously accessible 17,014 km^2 of habitat lying above the Mactaquac Dam (RK 140), the estimated footprint of overall potential hydroelectric generation impacts on eels increases by approximately 52% from the current 15,375 km^2 to 23,490 km^2.

Restoration of connectivity via effective upstream passage to and downstream passage from, the upper reaches of the Saint John River that were historically available to eels would result in an approximately 18% percent increase in potential rearing habitat for the Maritimes Region eel population.

Eel and elver fisheries occurring within the same river drainages account for 11% of available habitat. Eel and elver fisheries occurring within drainages with hydroelectricity generating facilities accounted for 4.1% and 2.0% of available habitat in 2015 and 2016, respectively.

Elvers

The geographic footprint of the elver fishery has never represented more than about 35% (Table 10) of the Maritimes Region drainage area. The area fished has been less than 30% of the habitat available to eels since 2015 (Table 10). The potential effects of directed elver fishing on eel status, in the absence of other sources of human-induced mortality, are therefore likely modest, at both the regional and Atlantic Canada coastal levels.

However, it warrants mention that presence of existing eel fisheries within specific river drainages is probably not the sole reason that elver fisheries do not occur there. A number of rivers that were assessed for elver fishery potential during the years of exploratory fishing and the early years of commercial fishing did not show commercial potential (DFO, pers. comm.). Landed value and the logistical challenges of fishing specific locations may have been considerations in decisions to not continue to fish, along with the fact that fishing success increases as the area of receiving habitat increases (Figure 14). Many of the rivers that were abandoned during the years of experimental fishing, and the early years of the commercial fishery, have not been re-visited to assess elver fishing potential. It is, therefore, not known if elver availability in abandoned drainages is low overall, relative to the Maritimes Region river drainages where elver fishing is currently practiced.

Eel and Elver Fisheries

Eel and elver fisheries have the largest combined geographic footprints (total drainage area for each minus area of overlapping fisheries) of any of the human activities considered, with 62,704 km^2 (66%) and 60,967 km^2 (65%) of drainage area fished during 2015 and 2016. The potential exists for the area subjected to fishing to increase with time either through greater participation in the eel fishery (both in NB and NS) or by exchange of rivers presently fished for elvers for those that are larger in drainage area.

FISHERIES INDEPENDENT

Elver Abundance Indices

Annual elver run size to the East River-Chester (ER-C; kg wet-weight) was strongly and positively correlated with the East River-Sheet Harbour index (ER-SH; n) for the 4 years of overlap between the two data series:

$$\text{ER-C} = 12.33 + 0.00075\text{ER-SH} \quad (n = 4,\ r^2 = 0.97,\ p = 0.015).$$

Predicted run size to East River-Chester for the years 1990–1995 varied between 93 kg (1995) and 313 kg (1991) with no clear trend with time (Table 13, Figure 15). The observed 1999 total run-size estimate of 83 kg represents the series low. The observed 2018 total run-size estimate of 896 kg represents the series high. The corresponding run sizes, in terms of number of fish, were approximately 530,000 and 3,800,000 for 1999 and 2018, respectively.

Parameter estimates (with 95% Confidence Interval) resulting from the commercial catch versus observed East River-Chester escapement (kg) were β_0 = 4.46 (3.83, 5.08), β_1 = 1.50 (0.66, 2.32) and β_2 = -1.15 (-1.88, -0.44). All model coefficients were statistically significant as 95% credible intervals did not contain 0. The incremental parameter, β_2, lowered the slope of the relationship between CPUE and escapement. Specifically, in years where quota was not met, the slope of the relationship becomes $\beta_2 + \beta_1$ or 0.35 (-1.22,1.88, non significant). Model predictions for the years 2003 to 2007, when the East River-Chester elver index project was not in operation, were less than 300 kg with the exception of 535 kg in 2006 (Table 13, Figure 16).

Mann-Kendall trend analyses applied to the East River-Chester observed run-size time series, the observed data plus the regression predicted 1990–1995 run-size estimates, the observed estimates for 1996–1999 replaced with the regression predictions, and the predicted series from the catch-escapement model, all exhibited a statistically significant increasing trend with time ($p \leq 0.05$; Table 14, Figures 15 and 16).

Substantive inter-annual variability in total run size is evident for all data series; adjacent runs can vary higher or lower by more than 50% (Table 13, Figure 15). The increase in annual elver run size to East River-Chester with time is nonetheless evident. Application of a LOWESS smoother with a span of 0.8 to both the observed run-size estimates, and those predicted from the modelling of escapement to commercial catch and effort (taking into consideration that the model did not accurately predict runs sizes in years that the quota was met and CPUE was high), indicated run sizes have increased by a factor of at least two since the onset of elver monitoring on East River-Chester in 1996 (Figure 16). The available data indicate that the average rate of increase in the East River-Chester annual elver run size has been between 50,000 and 70,000 elver per year, about 15 kg, since 1996, and about 12 kg per year since 1990.

Juveniles

The juvenile eel index, based on juvenile catches in the elver traps deployed on East River-Chester, exhibited no statistically significant trend with time irrespective of the inclusion of the 2017 count, considered to be a partial count (Table 14, Figure 17). The index was significantly statistically correlated with the total elver run size of the previous year ($n = 12$, $r^2 = 0.41$, $p < 0.03$) and more strongly statistically correlated with elver escapement past the fishery in the previous year ($n = 12$, $r^2 = 0.71$, $p < 0.01$). These results are interesting on the basis that they represent the first indication that eel abundances in East River-Chester, at a river age of 1^+ years, reflect the recruitment strength of their year-class to the river. As well, the stronger correlation with escapement versus total run size may be an indication that juveniles that recruit to freshwater as elvers represent a stronger component of the juvenile population in the lower portions of the river than do juveniles that recruit to seawater as elvers. Both contingents have been shown to be present in juvenile and adult East River-Chester eels (Jessop et al. 2002).

Elver and Silver Eel Production Estimates

Estimates of annual elver run size and escapement past the fishery, as number of elvers and total wet-weight (kg), were available for 16 years from East River-Chester (Table 13). The median bootstrapped ($n = 5{,}000$) estimates of recruitment and escapement scaled to drainage-area size (134 km^2) were 2.55 kg wet-weight and 13,110 elvers per km^2 of drainage.

Median estimates of escapement past the East River-Chester commercial elver fishery were 1.62 kg and 9,135 elvers per km^2 (Table 15, Figure 18).

Silver eel escapement from Oakland Lake, during the years when counts were considered to be near complete (2012–2015. 2017; Table 16), has varied from 5.7 to 8.0 eels per hectare (0.93 to 1.13 kg/ha) of lake habitat and 0.9 to 1.3 eels per hectare (0.15 kg to 0.18 kg per hectare) of drainage area (Table 16). Eel Pond yielded 8.1 eels (0.73 kg) per hectare of lake habitat and 2.6 eels (0.23 kg) per hectare of drainage area during 2015 (Table 16). Overall, these suggest that silver eel production is not high in these drainages.

Swim Bladder Parasite

Eels infected by *A. crassus*, can experience significant damage to their swim bladders. The pathological effects resulting from infection, which are better understood for the European Eel (*A. anguilla*), may lead to reduced foraging, lower energy reserves, and reduced swimming ability (Sprengel and Luchtenberg 1991, Palstra et al. 2007). These are all factors that could potentially reduce the ability of infected adult eels to migrate and spawn successfully in the Sargasso Sea (Barse and Secor 1999, Kirk 2003, Knopf 2006). A recent study (Warshafsky 2017) aimed at understanding the population-level effects of *A. crassus* on American Eel indicated that, although some test animals exhibited an ability to partially repair damage to their swim bladder, the annual survival rate of infected eels was 0.76 that of uninfected eels.

The distribution of the swim bladder parasite in the Maritimes Region was described as patchy at the time of the 2008 and 2009 surveys reported by Campbell et al. (2013). East River-Chester and Oakland Lake Stream were the only new detection locations since the 2008 and 2009 surveys, and these were the result of directed DFO-Industry monitoring. Effort to search for the presence of the parasite has been low.

The cumulative extent of occurrence of the parasite within Maritimes Region is, at minimal, 38,037 km^2 (40.6% of total), with eel and elver fishing having been concurrent with the presence of the parasite in as much as 35,163 km^2 (approximately 37% of total) and 4,771 km^2 (5% of total) of drainage area, respectively (Table 11). Protocols are in effect to disinfect elver (but not eel) fishing gear before gear is moved among discrete river drainages.

SPATIAL OVERLAP OF LARGE EEL AND ELVER FISHERIES

2. *What has been the annual extent of spatial overlap of the large eel and elver fisheries, since 2015?*

There is a policy of not authorizing elver fisheries in rivers which have a history of eel fishing within any of the three prior years. This policy has been reasonably effective in limiting the extent of overlap between the two fishery sectors to < 10% of the habitat available to eels (Table 11). There remains potential for the extent of overlap to increase, potentially significantly, in any year, depending upon the number of participants in the commercial eel fishery and their choice of fishing locations.

However, information concerning eel fishing activities in the most recent fishing year should not be considered comprehensive because not all eel fishers submit their logbooks for data entry at the end of the fishing season. This effectively imposes a two-year lag on the reporting of fishing locations, given that the eel fisheries can extend into November.

RECOMMENDED MORTALITY REFERENCE POINTS FOR EELS

3. *Based on a Spawner biomass Per Recruit (SPR) analysis, what are the recommended reference points for large eels to allow for escapement from fisheries and hydroelectric facilities, and is current mortality within those levels?*

Eel Fisheries

The outcomes of SPR analysis applied to the average life-history traits of Maritimes Region eel populations suggest that Fishing Mortalities (F) corresponding to $SPR_{30\%}$ and $SPR_{50\%}$ are 0.166 and 0.09 respectively (Figure 19).

It is not advisable at this time to assess whether current fishing activities within individual river drainages are within acceptable limits given that only 2 years of catch data, with limited, robust effort data, are available. It can, nonetheless, be noted that eel fishing occurs in less than half of the habitat available to eels at the regional level (Table 10). Overall removals by fishing might, therefore, be expected to be moderate relative to the overall productive capacity of the region. However, the potential for cumulative effects to arise from interactions with hydroelectric generation facilities within 6% of the available habitat that is shared with eel fisheries (Table 11) and from an additional 11% of the available habitat that is shared with elver fishing (Table 11) could temper the view that eel fisheries have a moderate impact on regional adult eel production. Significant mortality from either of these fisheries would require a potentially significant reduction in fishing mortality arising from the other (Figure 20).

Hydroelectric Facilities

There is very little information available concerning the existence and effectiveness of upstream and downstream bypass facilities for American Eel. Turbine mortality estimates for downstream migrating adult eels are available for only a single facility (Carr and Whoriskey 2008). Potential losses during the yellow eel stage, which can last for 2 decades or more, are not well understood, although indication that Maritimes Region yellow eels can migrate extensively between freshwater and tidal habitat (Jessop et al. 2002) demonstrates that the risk of mortality during downstream transit of hydroelectric generating facilities may not be limited to the single transit that is assumed for out-migrating silver eels.

Estimation of the overall impact of hydroelectric facilities on eel productivity is not presently possible.

Mortality reference points for silver eels assuming a single interaction (transit) through a hydroelectric generating facility can be estimated from SPR analysis. Application to the average life-history traits of Maritimes Region eel populations suggest that the hydroelectric associated mortalities corresponding to $SPR_{30\%}$ and $SPR_{50\%}$ are 1.204 and 0.693, respectively (Figure 21).

RECOMMENDED MORTALITY REFERENCE POINTS FOR ELVER FISHERIES

4. *What are the recommended F-based reference points for elver fisheries in the Maritimes Region? What is the status of current exploitation relative to the reference points?*

The outcomes of SPR analysis applied to the average life-history traits of Maritimes Region eel suggest that Fishing Mortalities (F) on elvers corresponding to $SPR_{30\%}$ and $SPR_{50\%}$ are 1.2 and 0.69 respectively (Figure 22).

The observed elver run-sizes less the elver escapement estimates on East River-Chester for the years 1996–2002, 2008–2018 indicate that this localized fishery has removed between 5% to 65% of the run (Table 17, Figure 23). The annual estimates all lie below F_{SPR50} = 0.69 (Figure 23). The median exploitation rates estimated from the modelled catch and effort data are in general agreement with the observed exploitation rates, but where significant departures occur from observed values the modeled values are higher and above SPR_{30} (Figure 23).

Exploitation rates were estimated using the catch history for each river-specific fishery. The number of elvers available to capture was estimated by multiplying river drainage area by estimated median size (kg) of the elver run to East River-Chester, scaled to 1 km^2 of habitat (Table 15, Figure 18). The plot of exploitation rate (annual landings by river for all years), versus the (natural log transformed) drainage area (km^2) for the river from which they were reported (Figure 24), indicated there is a risk of overfishing elver runs to drainages with areas smaller than approximately 250–300 km^2 . The cumulative area of the drainages < 250 km^2 that support elver fisheries is small (around 6%) relative to the total habitat available to eels, but represents about 20% of the total area fished for elvers and about 70–73% of the drainages that have been actively fished annually, beginning in 2015.

The catch history of the fishery shows that the arbitrary river quota of 400 kg wet-weight has not been achieved on rivers smaller than 250 km^2 and infrequently approached on the larger river drainages (Figures 25 and 26). This outcome may be a consequence of a lower-than-anticipated availability of elvers to capture, perhaps owing to geographic heterogeneity in run size. However, the relatively uniform across-river limits on the amounts of gear that can be set could be contributing to an inverse relationship between fishing power and river area.

Evaluation of the performance of the regional fishery, with consideration of fishing effort, relative to the mortality rates corresponding to SPR_{30} and SPR_{50} (Figures 25 and 26) indicate there is a need to adjust river quotas on the basis of the habitat area associated with the rivers where authorized elver fisheries occur. SPR_{30} (F = 1.2) is recommended as the limit reference point, provided elver recruitment per km^2 remains above the long-term median which is currently 2.34 kg/km^2. Most river-specific exploitation rates have been below the exploitation equivalent of F_{SPR30} with the exception of the smaller rivers in some years. While run sizes predicted from models that relate elver catch and effort in the commercial fishery to total run size yielded similar outcomes to application of the observed catch and escapement data for East River-Chester, the preference, moving forward, would be to use observed total run size and escapement whenever possible.

IMPLICATIONS FOR EXISTING MANAGEMENT MEASURES

5. *What are the implications for existing management measures in the eel and elver fisheries if these reference points are adopted?*

This assessment was not able to consider the current status of the eel fishery in any detail, including in relation to the recommended mortality reference points. The geographic footprint of the regional fishery has been shown to be relatively modest. Participation is currently low, relative to potential (licences available) and historical participation, as are the amounts of gear under active licences. In combination, this in part explains why current landings are low relative to past years. These factors suggest that working towards maintaining the spatial separation of eel and elver fisheries may offer the greatest conservation benefit until sufficient data are acquired to assess the status of the eel fishery with consideration of cumulative mortality arising from interaction with the elver fishery and hydroelectric utilities.

Elver fishery quotas will need to be revised minimally at the river-specific level to reduce fishing mortality to below the limit reference point. The weights of elvers associated with run strength scaled to a 1 km^2 area that corresponds to SPR_{30} and SPR_{50} should offer some guidance on acceptable river-specific quotas. These weights are presently estimated to be 1.61 kg/km^2 and 1.15 kg/km^2 for SPR_{30} and SPR_{50}, respectively.

ASSESSMENT SCHEDULE AND CONTENT FOR UPDATES

6. *What is the schedule for future assessments of American Eel, and what will be included in the updates provided between assessments?*

The availability, virtually within the same calendar year of the fishery, of robust fishery-dependent and fishery-independent information concerning elver recruitment, in combination with life-history characteristics that result in a one to two decade lag in the response of river populations, measured as silver eel escapement, to changes in recruitment indicate that assessments, could occur about every five years.

The serial increase in elver recruitment, albeit with significant inter-annual variability (Table 14; Figures 15 and 27), indicates that the potential productivity of Maritimes Region eels is not static, and subject to change. The recommended approach to establishing reference points to support precautionary management strategies under scenarios of changing productivity is to use the longest possible time series of status indicators for the stock, and to establish the reference points on the basis of the long-term mean of the series (DFO 2013). The running median abundance for the East River-Chester elver recruitment index (estimated present value = 2.34 kg/km^2) is accordingly recommended as the principle indicator of status. A decline in elver recruitment below the long-term median would require a re-evaluation of mortality reference points.

There remains, however, a more immediate need to better understand the status of river-resident eel populations, the impacts of hydroelectric generating facilities on adult eel escapement, and to evaluate the interactions between eel and elver fisheries, and between eel fisheries and hydroelectric-generating facilities, in order to better manage eels in an integrated precautionary management framework (DFO 2009). Five years of eel fishery catch and effort data will be available by January 2021 (for the 2015–2020 fishing years). Recent changes in the reporting structures for elver fishing activities may yield better information concerning gear- and location-specific catch and effort data. These data could support further investigation into geographic heterogeneity in elver run strength. These factors may justify an assessment in mid to late 2021.

Updates on status could include the reporting of the annual run size and escapement at East River-Chester, the counts of juveniles that result from operating the East River elver index, and, depending on the timing of the update, the total landings from the commercial elver fishery in the current year. The long-term and 3-year running mean of elver recruitment (Figure 27) could be updated as a means to assess whether there has been a change in elver recruitment status that may warrant a more detailed evaluation.

Information concerning the eel fishery could minimally include licencing and aggregate catch information for the most recent year of availability. Suggested inputs to the annual summary are the number of licences available, the number of licences that were issued and that were active, the amount of gear associated with active licences, and the total annual catch for each province.

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TABLES

Table 1. The amount and type of gear authorized for the Maritimes Region elver fishery. The quantities of each gear type vary among the 9 valid licences.

Gear type	Total number	Notes
Dip nets	156 (56 can be used with stationary wings)	Length of stationary wings varies and is specified in licence conditions.
Elver traps	147	Elver traps (fine-meshed fyke nets) are considered “eel traps” under the MPFRs. Limits on the amount that can be set in individual rivers are specified in licence conditions. Maximum size limits for elver traps vary and are specified in licence conditions.
Elver pots	34	Elver pots are considered “eel pots” under the MPFRs.
Push trawls	3	Size restriction is in licence conditions. Maximum size is 2.2 m in width and 1.3 m in height.
Pipe traps	10	Size restrictions are stated in licence conditions.

Table 2ai. Average (± Standard Deviation) annual American Eel catch (per 100 m^2 swept area) within tributaries located below Mactaquac Dam situated on the main stem of the Saint John River, New Brunswick. Blanks (-) represent no available data.

	Canaan				Gaspereau				Hammond				Kennebecasis			
	Sites	Eels	Eels/100m²		Sites	Eels	Eels/100m²		Sites	Eels	Eels/100m²		Sites	Eels	Eels/100m²	
Year	**n**	**n**	**Mean**	**SD**	**n**	**n**	**Mean**	**SD**	**n**	**n**	**Mean**	**SD**	**n**	**n**	**Mean**	**SD**
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	4	91	1.91	3.81	5	0	0.00	0.00
1995	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1996	-	-	-	-	-	-	-	-	4	67	0.80	0.58	1	20	1.22	0.00
1997	-	-	-	-	-	-	-	-	4	67	0.95	0.60	-	-	-	-
1998	2	44	1.69	1.25	-	-	-	-	4	33	0.52	0.37	5	11	0.16	0.20
1999	2	33	1.94	0.59	1	0	0.00	0.00	4	50	0.73	0.42	5	25	0.29	0.32
2000	-	-	-	-	-	-	-	-	2	0	0.00	0.00	5	15	0.17	0.23
2001	2	25	1.36	0.81	-	-	-	-	4	66	0.66	0.46	-	-	-	-
2002	2	28	1.99	1.31	-	-	-	-	4	18	0.23	0.13	-	-	-	-
2003	2	33	1.85	0.34	-	-	-	-	5	55	0.77	0.31	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2008	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**10**	**163**	**-**	**-**	**1**	**0**	**-**	**-**	**35**	**447**	**-**	**-**	**21**	**71**	**-**	**-**

Table 2aii. Average (± Standard Deviation) annual American Eel catch (per 100 m² swept area) within tributaries located below Mactaquac Dam situated on the main stem of the Saint John River, New Brunswick. Blanks (-) represent no available data.

	Keswick				Nashwaak				Nerepis				Salmon (Chipman)			
	Sites	Eels	Eels/100m²		Sites	Eels	Eels/100m²		Sites	Eels	Eels/100m²		Sites	Eels	Eels/100m²	
Year	**n**	**n**	**Mean**	**SD**	**n**	**n**	**Mean**	**SD**	**n**	**n**	**Mean**	**SD**	**n**	**n**	**Mean**	**SD**
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	4	134	2.37	2.75	5	56	0.57	0.78	-	-	-	-	-	-	-	-
1993	5	65	1.36	1.46	10	188	1.47	1.40	-	-	-	-	-	-	-	-
1994	5	0	0.00	0.00	14	95	0.46	0.79	-	-	-	-	-	-	-	-
1995	4	87	2.11	1.33	8	55	0.62	0.90	-	-	-	-	-	-	-	-
1996	4	39	0.88	0.78	9	136	1.39	0.66	-	-	-	-	-	-	-	-
1997	4	18	0.47	0.33	9	130	1.04	0.69	-	-	-	-	-	-	-	-
1998	3	47	1.60	0.28	13	159	1.22	0.94	2	9	0.68	0.28	-	-	-	-
1999	4	35	0.87	0.61	13	106	0.70	0.68	1	10	0.92	0.00	2	0	0.00	0.00
2000	3	5	0.17	0.22	9	163	1.37	1.01	-	-	-	-	-	-	-	-
2001	4	61	1.49	0.55	12	220	1.50	0.78	-	-	-	-	-	-	-	-
2002	4	72	1.71	1.30	9	146	1.36	1.05	-	-	-	-	-	-	-	-
2003	5	57	1.13	0.85	12	77	0.52	0.55	-	-	-	-	-	-	-	-
2004	-	-	-	-	26	541	2.05	2.08	-	-	-	-	-	-	-	-
2005	-	-	-	-	25	408	1.47	1.18	-	-	-	-	-	-	-	-
2006	-	-	-	-	26	225	0.85	0.74	-	-	-	-	-	-	-	-
2007	-	-	-	-	26	392	1.43	0.99	-	-	-	-	-	-	-	-
2008	-	-	-	-	16	215	1.27	1.11	-	-	-	-	-	-	-	-
2009	-	-	-	-	11	139	1.09	0.84	-	-	-	-	-	-	-	-
2010	-	-	-	-	10	146	1.08	0.95	-	-	-	-	-	-	-	-
2011	-	-	-	-	10	76	0.62	0.36	-	-	-	-	-	-	-	-
2012	-	-	-	-	10	213	1.73	1.08	-	-	-	-	-	-	-	-
Total	**49**	**620**	**-**	**-**	**283**	**3,886**	**-**	**-**	**3**	**19**	**-**	**-**	**2**	**0**	**-**	**-**

Table 2b. Average (± Standard Deviation) annual American Eel catch (per 100 m² swept area) within tributaries located above Mactaquac Dam situated on the main stem of the Saint John River, New Brunswick. Blanks (-) represent no available data.

	Becaguimec				Meduxnekeag				Salmon (Vic)				Shikatehawk				Tobique			
	Sites	Eels	Eels/100m²		Sites	Eels	Eels/100m²		Sites	Eels	Eels/100m²		Sites	Eels	Eels/100m²		Sites	Eels	Eels/100m²	
Year	n	n	Mean	SD	n	n	Mean	SD	n	n	Mean	SD	n	n	Mean	SD	n	n	Mean	SD
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	-	-	-	4	0	0.00	-	-	-	-	-	2	0	0.00	-	3	0	0.00	-
1993	5	0	0.00	-	5	0	0.00	-	2	0	0.00	-	5	0	0.00	-	-	-	-	-
1994	4	0	0.00	-	5	0	0.00	-	-	-	-	-	5	0	0.00	-	5	0	0.00	-
1995	5	0	0.00	-	5	0	0.00	-	3	0	0.00	-	4	0	0.00	-	10	0	0.00	-
1996	5	0	0.00	-	4	0	0.00	-	3	0	0.00	-	5	0	0.00	-	18	1	0.00	-
1997	5	0	0.00	-	5	0	0.00	-	5	0	0.00	-	2	0	0.00	-	17	0	0.00	-
1998	5	0	0.00	-	5	0	0.00	-	5	0	0.00	-	4	0	0.00	-	17	0	0.00	-
1999	5	0	0.00	-	5	0	0.00	-	5	0	0.00	-	5	0	0.00	-	18	0	0.00	-
2000	5	0	0.00	-	5	1	0.01	-	5	0	0.00	-	5	0	0.00	-	16	0	0.00	-
2001	5	0	0.00	-	4	0	0.00	-	5	0	0.00	-	5	0	0.00	-	17	0	0.00	-
2002	5	0	0.00	-	4	0	0.00	-	5	0	0.00	-	5	0	0.00	-	14	0	0.00	-
2003	5	0	0.00	-	3	0	0.00	-	5	0	0.00	-	5	0	0.00	-	17	0	0.00	-
2004	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	58	0	0.00	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	1	0	0.00	-	58	0	0.00	-
2006	-	-	-	-	-	-	-	-	5	0	0.00	-	-	-	-	-	57	0	0.00	-
2007	7	0	0.00	-	4	0	0.00	-	6	0	0.00	-	6	0	0.00	-	29	0	0.00	-
2008	7	0	0.00	-	4	0	0.00	-	5	0	0.00	-	7	0	0.00	-	28	0	0.00	-
2009	7	0	0.00	-	4	0	0.00	-	5	0	0.00	-	7	0	0.00	-	17	0	0.00	-
2010	5	0	0.00	-	4	0	0.00	-	8	0	0.00	-	5	0	0.00	-	18	0	0.00	-
2011	5	0	0.00	-	4	0	0.00	-	5	0	0.00	-	5	0	0.00	-	18	0	0.00	-
2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16	0	0.00	-
Total	85	0	-	-	74	1	-	-	77	0	-	-	83	0	-	-	451	1	-	-

Table 3. Summary of the electrofishing-based abundance indicators used in Cairns et al. (2014) for Maritimes Region. Abundance is estimated as the mean annual number of eels caught per 100 m² during the first sweep. Blanks (-) represent no available data.

	Eels per 100 m² during the first sweep		
Year	St. Marys	Lahave	Nashwaak
1985	6.89	-	-
1986	6.48	-	-
1987	-	-	-
1988	-	-	-
1989	-	-	-
1990	-	-	-
1991	-	-	3.10
1992	-	-	0.73
1993	-	-	1.18
1994	-	-	0.46
1995	6.61	0.81	0.62
1996	3.51	-	1.39
1997	5.04	1.60	1.04
1998	8.45	-	1.22
1999	5.42	-	0.70
2000	1.66	3.64	1.37
2001	1.68	1.90	1.50
2002	1.40	1.86	1.36
2003	1.83	0.57	0.52
2004	0.47	0.46	2.05
2005	1.41	0.45	1.47
2006	1.11	0.31	0.85
2007	1.90	0.05	1.43
2008	0.80	0.18	1.27
2009	1.03	0.44	1.09
2010	1.59	0.86	1.08
2011	1.45	0.41	0.62
2012	0.94	0.46	1.73
2013	1.36	0.51	0.52
2014	1.25	0.48	2.03
2015	1.66	0.71	1.38

Table 4. Characteristics of the Oakland Lake Stream and Eel Pond Brook coastal drainages where adult (silver) eel counts have been conducted in Maritimes Region.

	Area (ha)		
System	**Catchment**	**Lake Habitat**	**Sub-Area**
Oakland Lake Stream	406	Oakland Lake	**66**
Eel Pond Brook	370	Eel Pond	76
		East Lake	21
		Otter	4
		Squints Lake	16
		Total (Lake)	**117**

Table 5. Life-history input parameters in the Spawner biomass Per Recruit model.

		Length~LN(μ,σ)		M~U(X1,X2)		Mat~Beta(α,β)	
	Age	μ	σ	X1	X2	α	B
Age Specific	0	2.097	0.166	0.593	1.46	49.9	0.1
	1	2.65	0.282	0.069	0.171	49.9	0.1
	2	2.981	0.235	0.031	0.076	49.9	0.1
	3	3.25	0.152	0.026	0.063	49.9	0.1
	4	3.336	0.13	0.022	0.055	49.9	0.1
	5	3.535	0.209	0.02	0.05	49.9	0.1
	6	3.613	0.23	0.019	0.046	49	1
	7	3.705	0.26	0.017	0.043	48	2
	8	3.796	0.254	0.016	0.04	47	3
	9	3.94	0.153	0.015	0.038	46	4
	10	3.84	0.285	0.015	0.036	45	5
	11	4.318	0.101	0.014	0.035	30	20
	12	4.148	0.129	0.014	0.033	28	22
	13	4.114	0.138	0.013	0.032	28	22
	14	4.236	0.138	0.013	0.031	28	22
	15	4.251	0.09	0.012	0.03	28	22
	16	4.275	0.094	0.012	0.029	28	22
	17	4.207	0.107	0.012	0.028	28	22
	18	4.261	0.088	0.011	0.028	28	22
	19	4.233	0.105	0.011	0.027	28	22
	20	4.177	0.09	0.011	0.026	28	22
	21	4.424	0.167	0.01	0.026	28	22
	22	4.262	0.154	0.01	0.025	28	22
	23	4.237	0.092	0.01	0.025	28	22
	24	4.183	0.067	0.01	0.024	28	22
	25	4.217	0.043	0.01	0.024	28	22
Weight at age		$W_L = 0.0007006L^{3.2332}$					
Mortality at Sea		$M_{atSea} \sim N(0.1, 0.01)$					
Fecundity at Length		$F_L = 18.2L^{2.9642}$					

Table 6. Summary of licences available, type of licence (commercial, commercial communal, recreational) and the type and amount of fishing gear authorized for use by year and province.

Year	Province	Licence Type	Licences Available	Licenced Gear (n)		
				Pots	Traps	Weirs
2015	**NEW BRUNSWICK**	Commercial	26	1,621	910	0
		Commercial Communal	1	240	80	0
	NOVA SCOTIA	Commercial	275	19,939	1,244	24
		Commercial Communal	13	750	43	2
		Recreational	112	696	66	0
	2015 Totals		**427**	**23,246**	**2,343**	**26**
2016	**NEW BRUNSWICK**	Commercial	27	1,721	910	0
		Commercial Communal	1	240	80	0
	NOVA SCOTIA	Commercial	268	19,819	1,243	25
		Commercial Communal	13	750	43	2
		Recreational	100	626	62	0
	2016 Totals		**409**	**23,156**	**2,338**	**27**

Table 7. Summary of commercial fishing licences available, the amounts of gear authorized to be set, the number of licences issued and that reported fishing activity versus not fishing, and the maximum amount of gear that could have been set by active licence holders by year, province, and county. The mean and standard deviation of authorized gear, licences reported as either fished or not fished and the amounts of gear associated with active licences for the years 1993 to 2004 are shown.

			Licences				Gear Under Licence (n)			Gear (Active Licences (n))		
Year	**Province**	**County**	**Issued**	**Reporting**	**Not Fished**	**Fishing**	**Pots**	**Traps**	**Weirs**	**Pots**	**Traps**	**Weirs**
2015	**NEW BRUNSWICK**	**ALBERT**	2	1	1	0	60	40	0	0	0	0
		CHARLOTTE	3	1	0	1	300	2	0	100	0	0
		QUEENS	5	5	3	2	240	320	0	0	120	0
		SAINT JOHN	11	8	6	2	701	288	0	175	25	0
		SUNBURY	3	3	1	2	120	160	0	120	80	0
		WESTMORLAND	1	1	1	0	200	20	0	0	0	0
		YORK	1	1	1	0	0	80	0	0	0	0
	New Brunswick Totals 2015		**26**	**20**	**13**	**7**	**1,621**	**910**	**0**	**395**	**225**	**0**
	NOVA SCOTIA	**ANNAPOLIS**	3	2	2	0	126	110	0	0	0	0
		CAPE BRETON	36	11	9	2	1,593	328	0	125	10	0
		COLCHESTER	4	2	1	1	230	6	2	30	0	0
		CUMBERLAND	6	4	4	0	1,075	49	0	0	0	0
		DIGBY	12	6	6	0	767	100	0	0	0	0
		GUYSBOROUGH	15	4	1	3	290	13	0	80	0	0
		HALIFAX	29	11	8	3	1,903	50	0	225	6	0
		HANTS	4	4	3	1	420	4	0	300	0	0
		KINGS	1	0	0	0	300	0	0	0	0	0
		LUNENBURG	26	15	13	2	3,090	3	1	200	2	0
		QUEENS	17	7	5	2	981	6	7	125	0	0
		RICHMOND	15	5	3	2	293	104	7	25	37	3
		SHELBURNE	37	26	21	5	3,785	123	4	450	3	0
		VICTORIA	13	6	5	1	340	108	2	25	57	0
		YARMOUTH	57	33	26	7	4,746	240	1	510	68	0
	Nova Scotia Totals 2015		**275**	**136**	**107**	**29**	**19,939**	**1,244**	**24**	**2,095**	**183**	**3**
	Grand Totals 2015		**301**	**156**	**120**	**36**	**21,560**	**2,154**	**24**	**2,490**	**408**	**3**
2016	**NEW BRUNSWICK**	**ALBERT**	2	0	0	0	60	40	0	0	0	0
		CHARLOTTE	4	3	3	0	480	2	0	0	0	0
		QUEENS	6	6	2	4	240	320	0	240	200	0
		SAINT JOHN	11	5	3	2	621	288	0	100	40	0
		SUNBURY	3	3	1	2	120	160	0	120	80	0

Year	Province	County	Licences Issued	Licences Reporting	Licences Not Fished	Fishing	Gear Under Licence (n) Pots	Gear Under Licence (n) Traps	Gear Under Licence (n) Weirs	Gear (Active Licences (n)) Pots	Gear (Active Licences (n)) Traps	Gear (Active Licences (n)) Weirs
		WESTMORLAND	1	1	1	0	200	20	0	0	0	0
		YORK	0	0	0	0	0	80	0	0	0	0
	New Brunswick Totals 2016		**27**	**18**	**10**	**8**	**1,721**	**910**	**0**	**460**	**320**	**0**
	NOVA SCOTIA	**ANNAPOLIS**	3	2	1	1	126	110	0	0	100	0
		CAPE BRETON	35	11	9	2	1,573	328	0	25	110	0
		COLCHESTER	4	4	3	1	230	6	2	30	0	0
		CUMBERLAND	6	3	1	2	1,075	49	0	600	30	0
		DIGBY	13	7	7	0	1,167	100	0	0	0	0
		GUYSBOROUGH	15	3	3	0	295	15	0	80	0	0
		HALIFAX	26	12	10	2	1,698	48	0	100	6	0
		HANTS	4	3	3	0	420	4	0	0	0	0
		KINGS	1	0	0	0	300	0	0	0	0	0
		LUNENBURG	23	14	13	1	2,965	3	0	25	0	0
		QUEENS	16	6	5	1	881	6	7	75	0	0
		RICHMOND	14	6	3	3	293	103	7	28	37	3
		SHELBURNE	38	23	19	4	3,860	123	6	400	0	0
		VICTORIA	12	4	4	0	290	108	2	0	0	0
		YARMOUTH	56	35	22	13	4,646	240	1	770	185	0
	Nova Scotia Totals 2016		**266**	**133**	**103**	**30**	**19,819**	**1,243**	**25**	**2,133**	**468**	**3**
	Grand Totals 2016		**293**	**151**	**113**	**38**	**21,540**	**2,153**	**25**	**2,593**	**788**	**3**
		Average	**NA**	**180**	**50**	**131**	**31,752**	**2,819**	**45**	**4,254**	**676**	**10**
1993 to 2004		**Standard Deviation**	**NA**	**35**	**22**	**27**	**1,654**	**177**	**5**	**963**	**255**	**6**

Table 8. Proportion of available commercial fishing licences reporting eel catches, and the proportion of the gear available to licence holders that fished, by Province and by Year. NA = Not Applicable

	Participation/Year		Proportion of Gear 2015			Proportion of Gear 2016		
Province	2015	2016	Pots	Fyke Nets	Weirs	Pots	Fyke Nets	Weirs
NB	0.269	0.296	0.244	0.247	NA	0.267	0.352	NA
NS	0.105	0.113	0.105	0.147	0.125	0.108	0.377	0.120
Combined	**0.120**	**0.130**	**0.115**	**0.189**	**0.125**	**0.120**	**0.366**	**0.120**

Table 9a. Eel catch by province and by year reported in commercial logbooks with records of sale and no records of sale. The total annual catch (kg) of the Saint John River fishery is shown as a proportion of the total catch for New Brunswick [p(NB)] and for the Maritimes region [p(Total)] eel fishery. The average (± 1 standard deviation) of the reported annual landings (mt) by Province for the years 1993 to 2004 are shown.

		Catch (kg)		Landings for the Saint John River		
Year	Province	Sold	Not Sold	kg	p(NB)	p(Total)
2015	**NB**	13,055	0	13,018	0.997	0.361
	NS	23,049	1,435	-	-	-
Annual Total (kg)		**36,103**	**1,435**	**-**	-	-
2016	**NB**	23,506	0	23,506	1.000	0.532
	NS	20,637	2,643	-	-	-
Annual Total (kg)		**44,143**	**2,643**	-	-	-

Table 9b. The average (± 1 standard deviation) of the reported annual landings (mt) by Province for the years 1993 to 2004 are shown.

Year	Province	Average Landings (mt)
1993 to 2004	**NB**	91 ± 27
	NS	73 ± 21
Total		**164 ± 44**

Table 10. Summary of area (km^2 and expressed as a proportion of total area) of river drainages that are under hydroelectric development, fished for eels, fished for elvers, and where eels have been infected with the swim bladder parasite, separated into the following time periods: time of construction of the Mactaquac Dam (1969); 1970–2014; and for the years 2015, 2016, and 2017.

Time Period	Activity	Drainages (n)	Area of Influence km^2	Area of Influence P(Total)
1969	**Hydroelectricity**	20	33,410	0.302
	Eel Fisheries	Poor Records	-	-
	Elver Fisheries	No Fishery	-	-
	Parasite	No Data	-	-
1970–2014	**Hydroelectricity**	19	16,396	0.175
	Eel Fisheries	Poor Records	-	-
	Elver Fisheries[1]	159	32,668	0.349
	Parasite	11	38,037	0.406
2015	**Hydroelectricity**	17	15,375	0.164
	Eel Fisheries	35	43,832	0.468
	Elver Fisheries	92	26,736	0.285
	Parasite	11	38,037	0.406
2016	**Hydroelectricity**	17	15,375	0.164
	Eel Fisheries	25	40,526	0.432
	Elver Fisheries	86	25,679	0.274
	Parasite	11	38,037	0.406
2017	**Hydroelectricity**	17	15,375	0.164
	Eel Fisheries	Not Available	-	-
	Elver Fisheries	83	25,794	0.275
	Parasite	Not Available	-	-

[1] Commercial elver fishing began in 1996

Table 11. Summary of area (km^2 and expressed as a proportion of total area) of river drainages that are under hydroelectric development, fished for eels, fished for elvers, and where eels have been infected with the swim bladder parasite for the years 2015 and 2016. The extent of overlap between two activities is shown.

				Extent of Overlap With		
Year	**Units**	**Activity**	**Area (km^2)**	**Eel**	**Elver**	**Parasite**
2015	**km^2**	**Hydroelectricity**	15,375	5,253	10,388	1,936
		Eel Fisheries	43,832	-	7,864	35,163
		Elver Fisheries	26,736	-	-	4,771
		Parasite	38,037	-	-	-
	P(Total)	**Hydroelectricity**	0.164	0.056	0.111	0.021
		Eel Fisheries	0.468	-	0.084	0.375
		Elver Fisheries	0.285	-	-	0.051
		Parasite	0.406	-	-	-
2016	**km^2**	**Hydroelectricity**	15,375	4,841	10,388	1,936
		Eel Fisheries	40,526	-	5,238	32,736
		Elver Fisheries	25,679	-	-	4,610
		Parasite	38,037	-	-	-
	P(Total)	**Hydroelectricity**	0.164	0.052	0.111	0.021
		Eel Fisheries	0.432	-	0.056	0.349
		Elver Fisheries	0.274	-	-	0.049
		Parasite	0.406	-	-	-

Table 12. Maritimes Region Elver annual Total Allowable Catch (TAC) (mt) and landings (mt) from Experimental and Commercial fishing for the years 1989 to 2017. The proportion of the TAC [P(TAC)] landed is shown. All weights are reported as wet-weights. Blanks represent no available data.

			Commercial Catch	
Year	**Fishery**	**TAC (mt)**	**mt**	**P(TAC)**
1989	Experimental	None	0.03	-
1990	Experimental	None	0.17	-
1991	Experimental	None	0.07	-
1992	Experimental	None	0.23	-
1993	Experimental	None	0.71	-
1994	Experimental	None	1.57	-
1995	Experimental	None	3.24	-
1996	Commercial	None	2.86	-
1997	Commercial	None	4.13	-
1998	Commercial	13.3	2.05	0.15
1999	Commercial	13.3	0.48	0.04
2000	Commercial	13.3	0.68	0.05
2001	Commercial	13.3	1.84	0.14
2002	Commercial	13.3	2.36	0.18
2003	Commercial	13.3	1.84	0.14
2004	Commercial	13.3	1.27	0.10
2005	Commercial	9.96	3.04	0.30
2006	Commercial	9.96	2.46	0.25
2007	Commercial	9.96	2.03	0.20
2008	Commercial	9.96	3.59	0.36
2009	Commercial	9.96	1.81	0.18
2010	Commercial	9.96	1.47	0.15
2011	Commercial	9.96	3.08	0.31
2012	Commercial	9.96	5.59	0.56
2013	Commercial	9.96	6.76	0.68
2014	Commercial	9.96	5.71	0.57
2015	Commercial	9.96	3.58	0.36
2016	Commercial	9.96	5.20	0.52
2017	Commercial	9.96	5.61	0.56

Table 13. Observed annual total elver run-size estimates for East River(ER)-Sheet Harbour (n; Years 1990–1999) and East River-Chester (ER-C; n and kg wet-weight, Years 1990–2002, 2008–2018). Predicted run size (kg) to the ER-Chester for the years 1990–1999 based upon linear regression with the East River-Sheet Harbour (ER-SH) estimates and for the years 1996–2018 based upon a model that related elver run size to the total annual catch/effort for the elver licence whose fishing areas include ER-Chester. NA = Not Applicable

	Total Run Size Estimates				
	ER-Sheet Harbour	East River-Chester			
Year	(n)	(n)	Kilograms	Regression	Catch Model
1990	218,300	NA	NA	189	NA
1991	376,000	NA	NA	313	NA
1992	219,200	NA	NA	190	NA
1993	134,100	NA	NA	120	NA
1994	309,900	NA	NA	262	NA
1995	101,500	NA	NA	93	NA
1996	336,500	1,367,609	277	282	256
1997	467,400	1,887,151	359	383	618
1998	109,200	594,729	117	99	217
1999	134,600	530,760	85	121	143
2000	NA	879,854	149	NA	140
2001	NA	647,516	120	NA	163
2002	NA	2,689,021	536	NA	857
2003	NA	NA	NA	NA	276
2004	NA	NA	NA	NA	225
2005	NA	NA	NA	NA	281
2006	NA	NA	NA	NA	535
2007	NA	NA	NA	NA	298
2008	NA	1,970,988	458	NA	404
2009	NA	1,426,196	280	NA	307
2010	NA	774,811	156	NA	241
2011	NA	2,390,790	468	NA	531
2012	NA	2,587,177	439	NA	398
2013	NA	2,214,696	387	NA	563
2014	NA	2,748,237	499	NA	737
2015	NA	1,430,167	277	NA	316
2016	NA	2,951,576	610	NA	512
2017	NA	1,150,707	253	NA	277
2018	NA	3,793,992	896	NA	311

Table 14. Mann-Kendall trend analyses statistics for the East River-Chester Elver (kg wet-weight) and Juvenile (n) indices. The Raw series (n = 18) represents the observed weights of elver runs for the years 1996–2002, 2008–2018. The 'With 1990–1995 Predictions" series extends the raw series back to 1990 using the predicted run sizes from regression analysis of the East River-Chester and East River-Sheet Harbour data sets. The 'With 1990–1999 Predictions' replaces the observed East River-Chester values for the years 1996–1999 with the model predictions. The run sizes predicted from the escapement model are for years 1996 to 2018. Juvenile counts with and without the 2017 counts were from the years1996–2001, 2002, 2010–2018. The Mann-Kendall statistics tau, Denominator and Score are shown along with two-tailed probability (p-value) and the direction of the trend if a statistically significant temporal trend at p ≤ 0.05 was detected. NS = Not Significant.

Series	n	tau	Denominator	Score	p-value	Trend
Raw	18	0.380	152	58	0.03	Increase
With 1990–1995 Predictions	24	0.378	275	104	0.01	Increase
With 1990–1999 Predictions	24	0.381	275	105	0.001	Increase
Escapement Model	23	0.296	253	75	0.05	Increase
Juveniles	16	0.167	120	20	0.39	NS
Juveniles minus 2017	15	0.257	105	27	0.20	NS

Table 15. Bootstrap (n = 5,000) estimates of mean elver recruitment and escapement per 1 km^2 of receiving drainage expressed as number of elvers and kilograms. The estimates are based on mean elver run-size estimates for the East River-Chester (Drainage Area = 137 km^2) for the years 1996–2001 and 2008–2018.

				Standard	Confidence Interval	
	Units	**Mean**	**Median**	**Error**	**2.5**	**97.5**
	n	13,314	13,110	4,073	5,969	21,800
Recruitment per 1 km^2 Drainage	**kg**	2.64	2.55	0.89	1.09	4.58
	n	9,819	9,135	3,690	3,989	17,968
Escapement per 1 km^2 Drainage	**kg**	1.81	1.62	0.86	0.68	3.89

Table 16. Number of silver eels sampled (Sampled), the average weight of sampled silver eels (M.Weight) (kg), the total weight of sampled silver eels (Silver) (kg), the estimated total weight of the annual run (Total) (kg) and the estimates of annual production per hectare (ha) by number (n) and weight (kg) relative to lake surface area and catchment area by year of sampling.

		Catch of Silver (Adult) Eel					Lake		Catchment	
Year	**Location**	**n**	**Sampled**	**M.Weight**	**Silver (kg)**	**Total (kg)**	**n/ha**	**kg/ha**	**n/ha**	**kg/ha**
2011[1]	Oakland Lake Stream	272	228	0.10	23.3	27.8	4.1	0.42	0.7	0.07
2012	Oakland Lake Stream	374	373	0.16	60.9	61.1	5.7	0.93	0.9	0.15
2013	Oakland Lake Stream	526	526	0.14	74.5	74.5	8.0	1.13	1.3	0.18
2014	Oakland Lake Stream	488	392	0.14	53.9	67.1	7.4	1.02	1.2	0.17
2015	Oakland Lake Stream	523	410	0.12	49.9	63.6	7.9	0.96	1.3	0.16
2016[1]	Oakland Lake Stream	153	144	0.14	19.3	19.3	2.3	0.29	0.4	0.05
2017	Oakland Lake Stream	385	307	0.12	41.5	41.5	5.8	0.63	0.9	0.10
2014[1]	Eel Pond Brook	214	203	0.10	20.7	21.8	1.8	0.19	0.6	0.06
2015	Eel Pond Brook	944	944	0.09	85.7	85.7	8.1	0.73 [2]	2.6	0.23

[1] Partial Counts

[2] 1.13 for Eel Pond Only

Table 17. Summary of observed total Run Size (kg and n), Escapement (kg and n), and the Proportion of the run removed by fishing (P(Fished)) by Year.

	Run Size		Escapement		P(Fished)	
Year	**kg**	**n**	**kg**	**n**	**kg**	**n**
1996	277	1,367,609	162	863,350	0.42	0.37
1997	359	1,887,151	196	1,145,448	0.45	0.39
1998	117	594,729	40	247,407	0.66	0.58
1999	85	530,760	83	521,936	0.02	0.02
2000	149	879,854	149	879,854	0.00	0.00
2001	120	647,516	99	544,885	0.18	0.16
2002	536	2,689,021	322	1,742,610	0.40	0.35
2008	458	1,970,988	196	1,182,193	0.57	0.40
2009	280	1,426,196	114	696,376	0.59	0.51
2010	156	774,811	56	361,804	0.64	0.53
2011	468	2,390,790	295	1,696,852	0.37	0.29
2012	439	2,587,177	311	2,073,432	0.29	0.20
2013	387	2,214,696	262	1,661,407	0.32	0.25
2014	499	2,748,237	269	1,657,916	0.46	0.40
2015	277	1,430,167	113	669,030	0.59	0.53
2016	610	2,951,576	496	2,377,902	0.19	0.19
2017	253	1,150,707	178	831,634	0.30	0.28
2018	896	3,793,992	835	3,592,404	0.07	0.05

FIGURES

Figure 1. Map of Fisheries and Oceans Canada Administrative regions.

Figure 2. Map of the Maritime Provinces showing the portions of southwest New Brunswick, Bay of Fundy Nova Scotia and Atlantic Coastal Nova Scotia that lie within the Maritimes Region. The Fisheries Statistical District boundaries (blue circles with white numbers) lying within the region represent the conventional basis for the reporting of eel landings for the years prior to 2015.

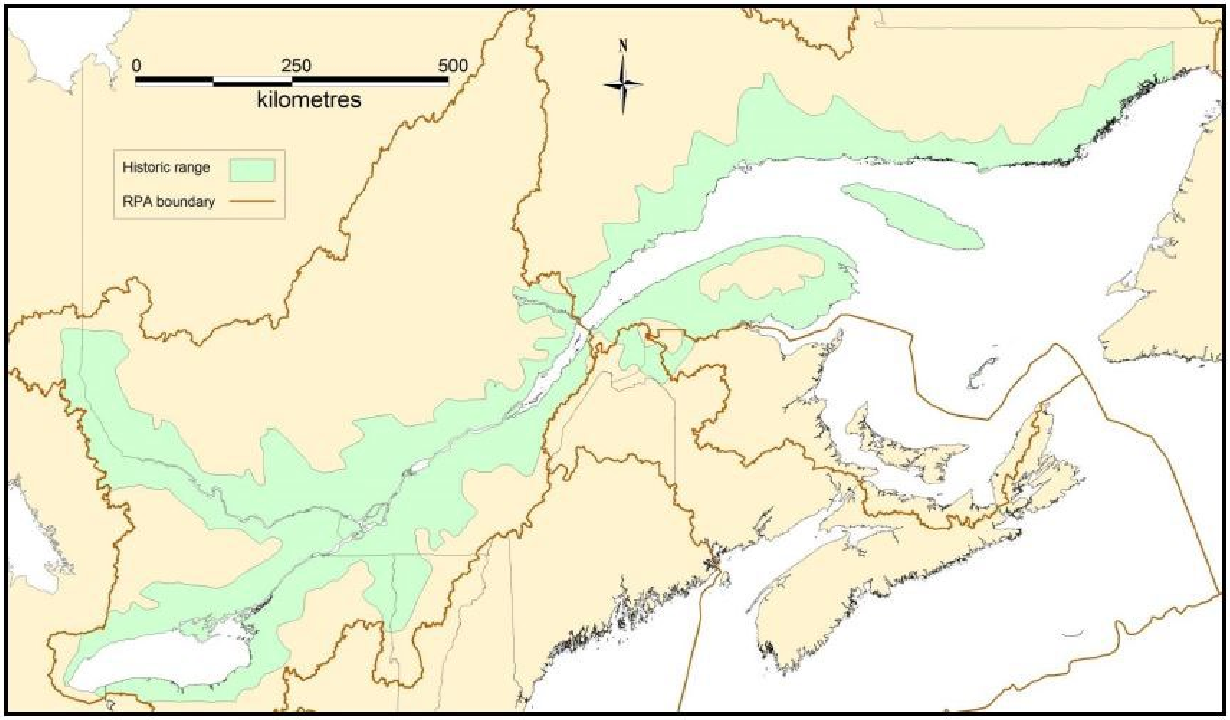


Figure 3. The boundary zone divisions for the American Eel defined in Cairns et al. (2014). The area of the Maritimes (Scotia-Fundy) Region boundary zone is estimated to be 118,846 km^2.

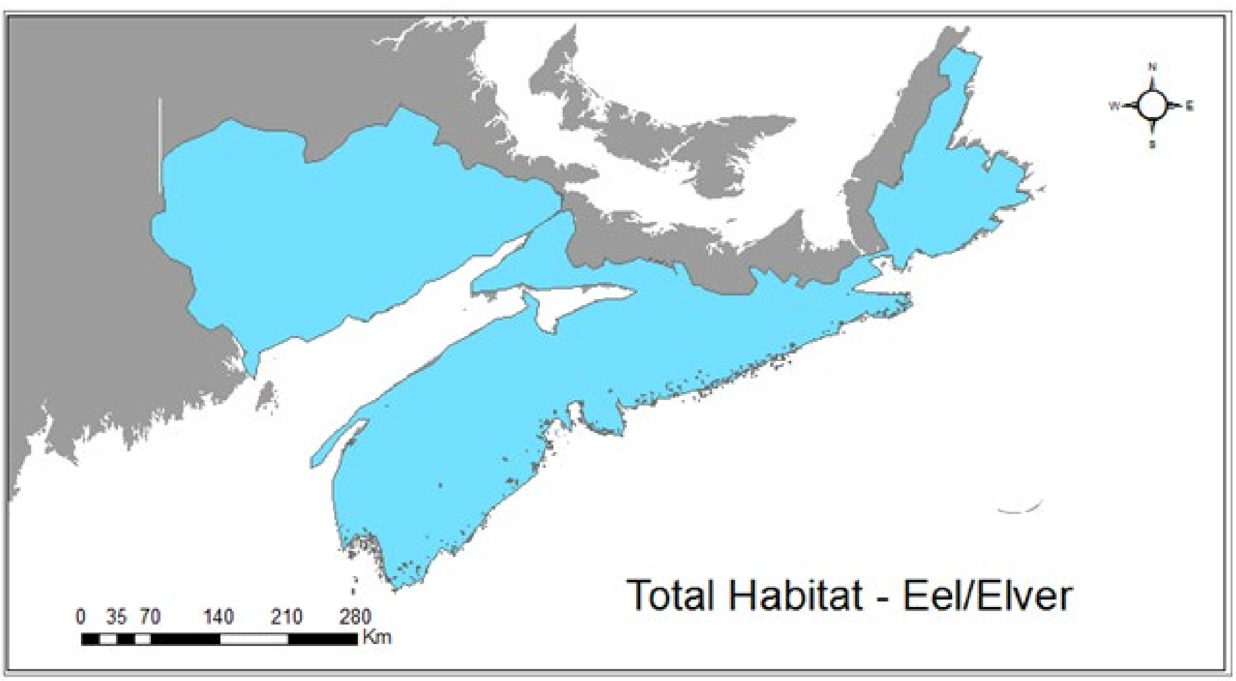


Figure 4. Estimated area within Maritimes Region that is accessible to American Eels.

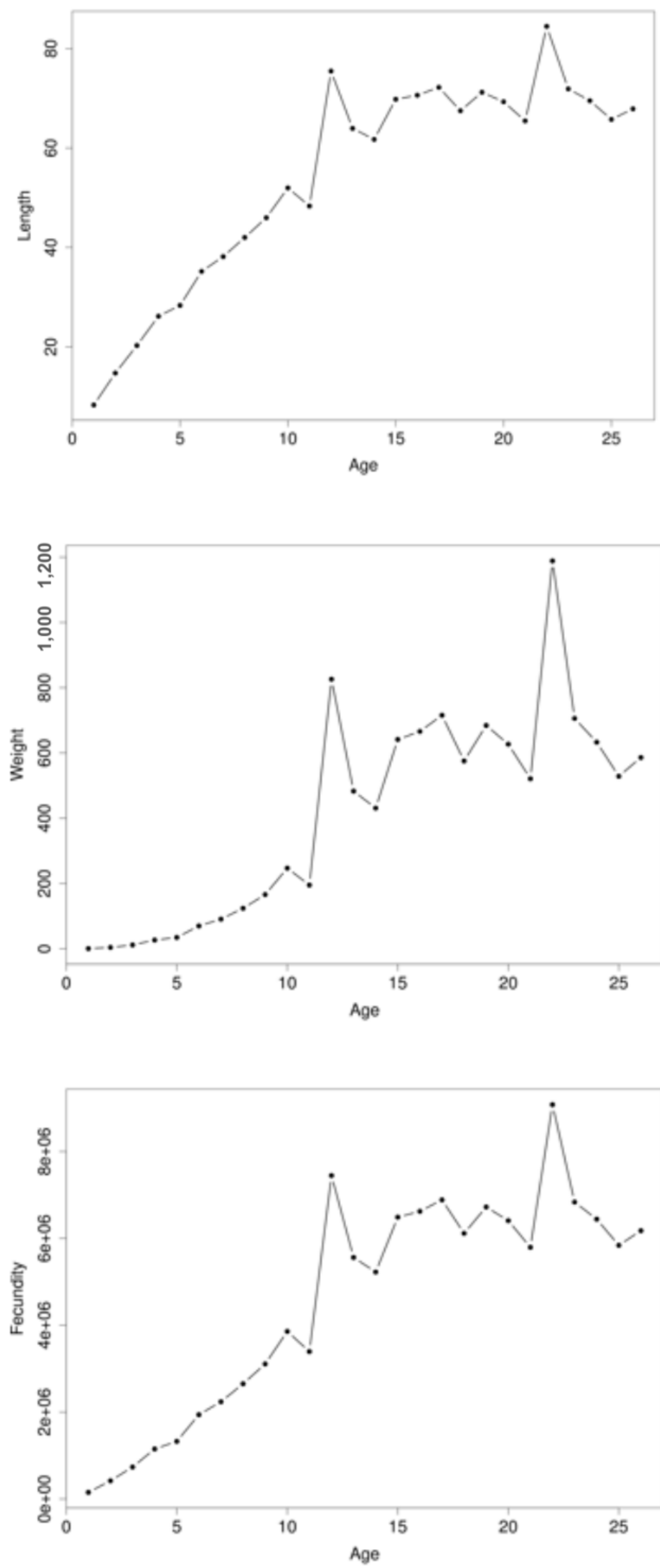
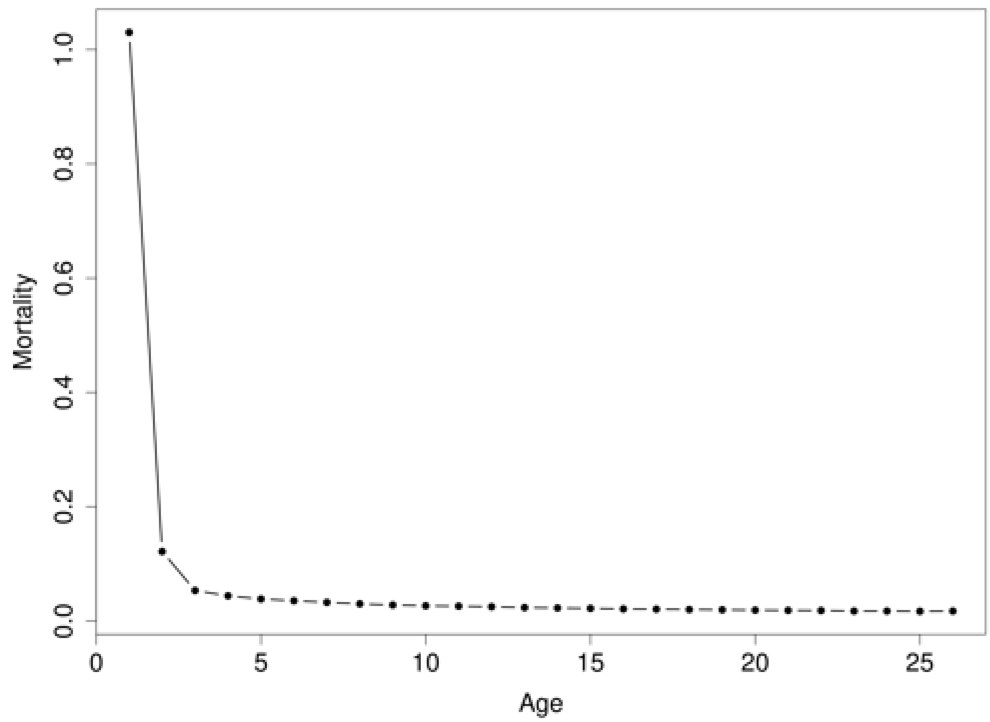


Figure 5. Plots of the (upper panel) total length (cm), (middle panel) total weight (g) and (lower panel) fecundity (thousands of eggs) at age (years) values used in SPR analysis.



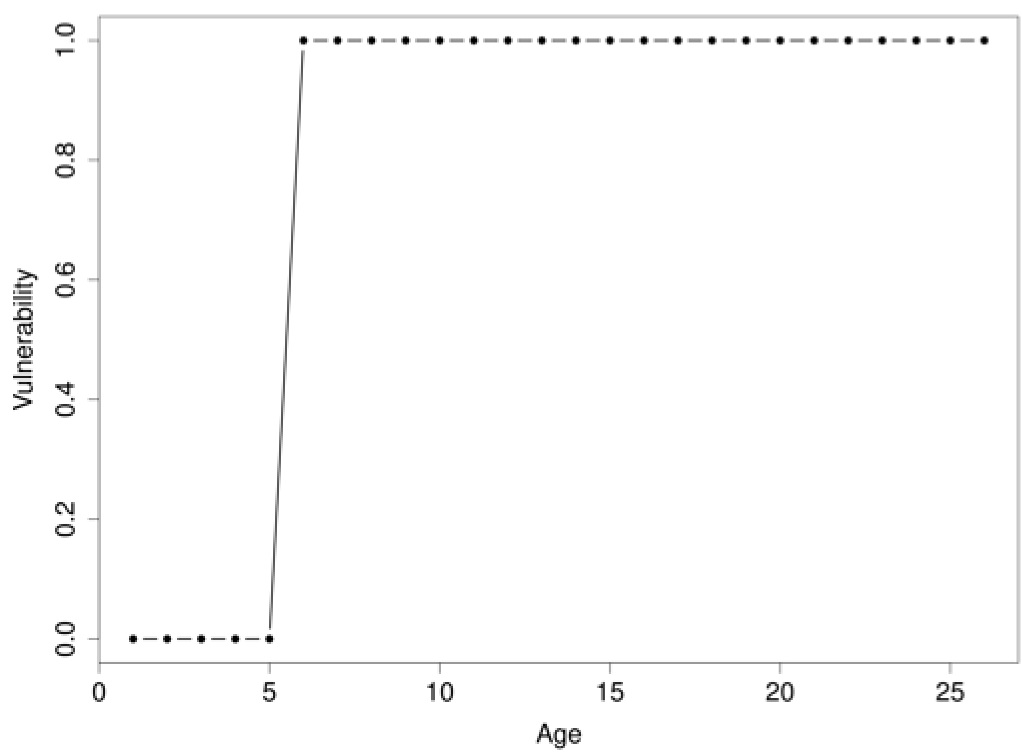


Figure 6. Upper panel: Natural mortality (M) estimates versus age (years) that were generated following Bevaqua et al. (2011). Lower panel: Vulnerability to human-induced mortality at age (years) assuming knife-edge vulnerability at 35 cm Total Length (TL).

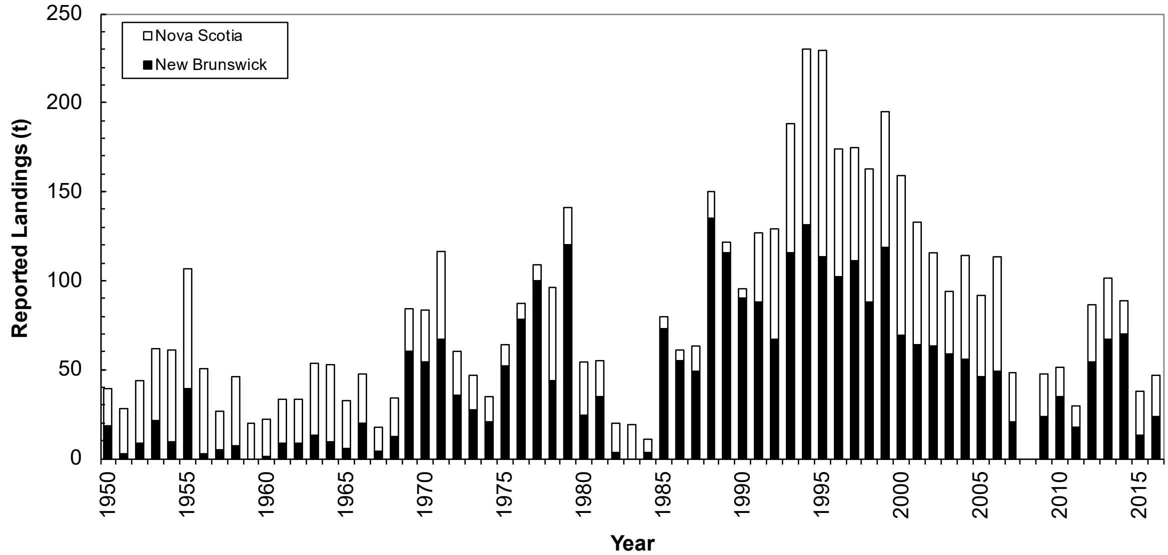


Figure 7. Reported landings (t) of from the Maritimes Region eel fishery for the years 1950 to 2016 by Province (open bars: Nova Scotia, solid bars: New Brunswick).

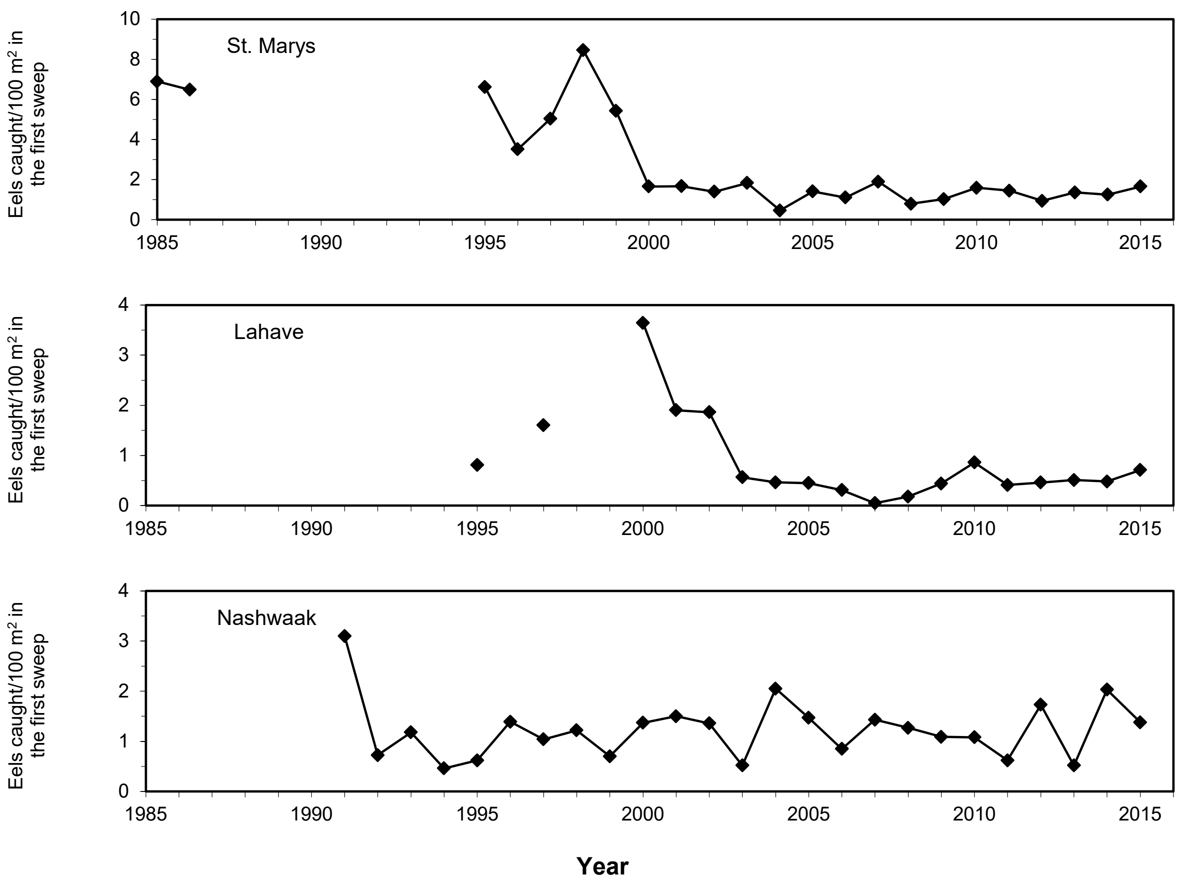


Figure 8. Update to 2015 of the electrofishing-based abundance indicators used in Cairns et al. (2014) for Maritimes Region. Abundance is estimated as the number of eels caught per 100 m² during the first sweep.

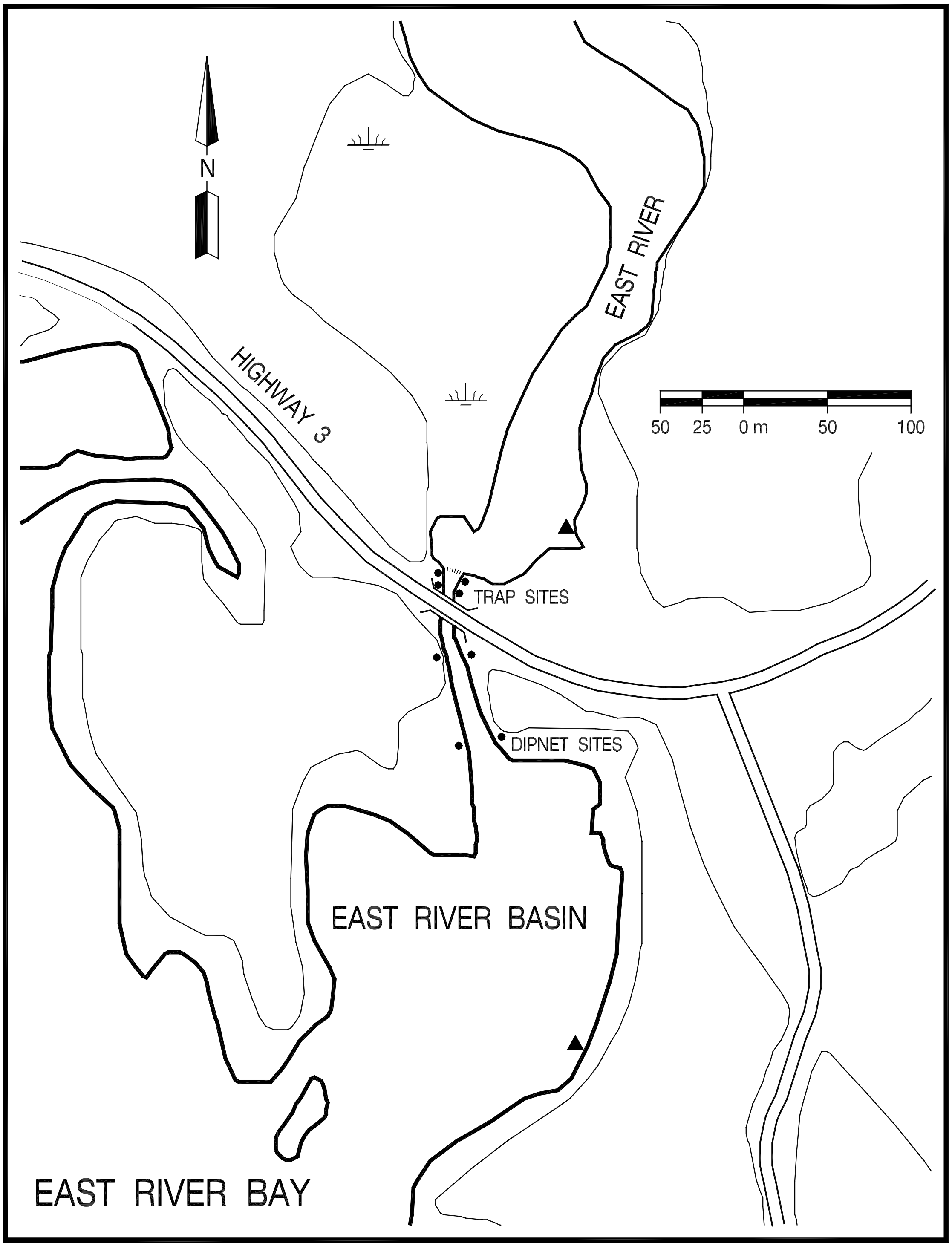


Figure 9. Elver trap and dip net fishing locations on the East River, Chester, Nova Scotia. Solid triangles indicate thermograph sites.

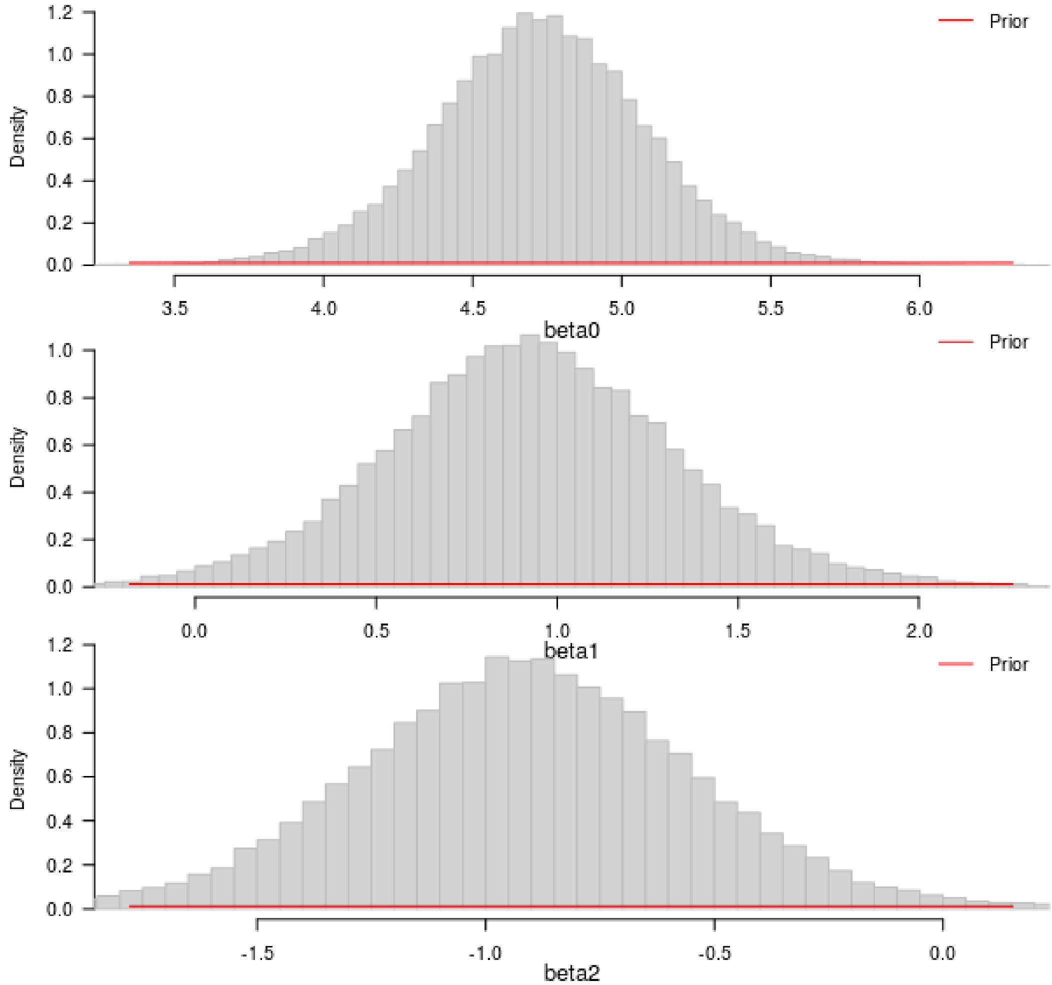


Figure 10. Frequency distribution plots of the prior (red lines) and posterior (bars) distributions of parameters ($\beta_0, \beta_1, \beta_2$) estimated in the escapement model using the Catch Per Unit Effort for the East River-Chester fishery as the predictor variable.

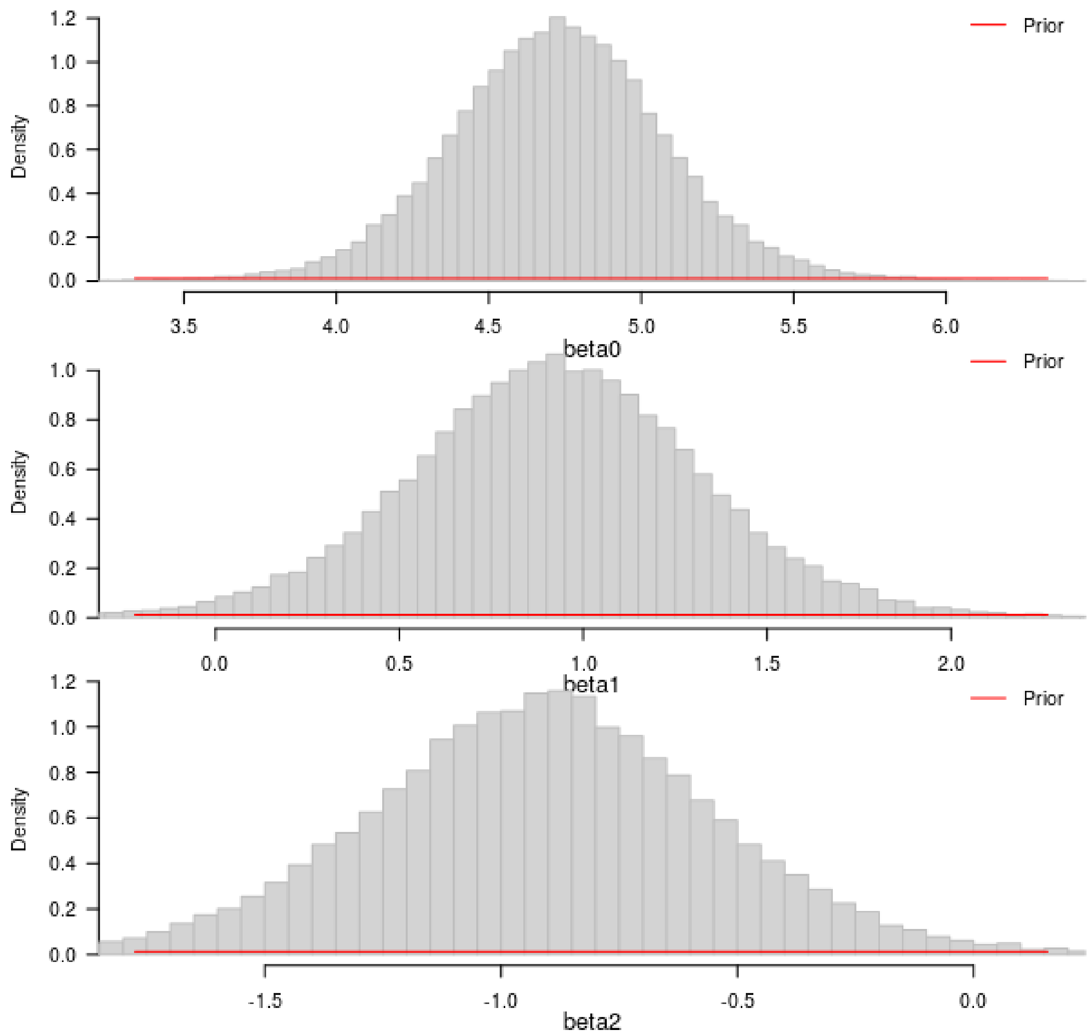


Figure 11. Frequency distribution plots of the prior (red lines) and posterior (bars) distributions of parameters ($\beta_0, \beta_1, \beta_2$) estimated in the escapement model using the Catch Per Unit Effort for the elver licence as the predictor variable.

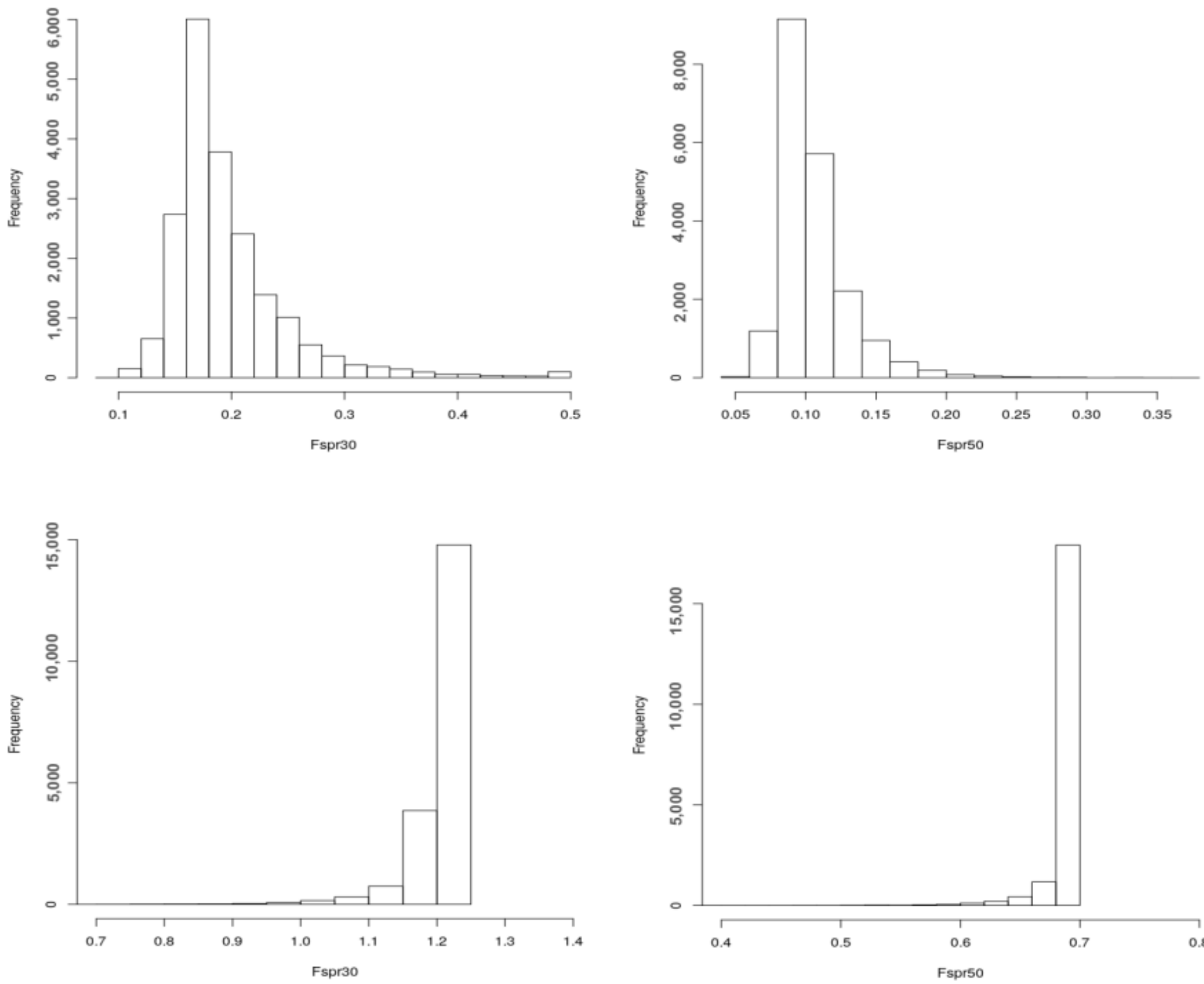


Figure 12. Stochastic F_{SPR30} and F_{SPR50} estimates for large eels (top left and right panels) and elvers (bottom left and right panels).

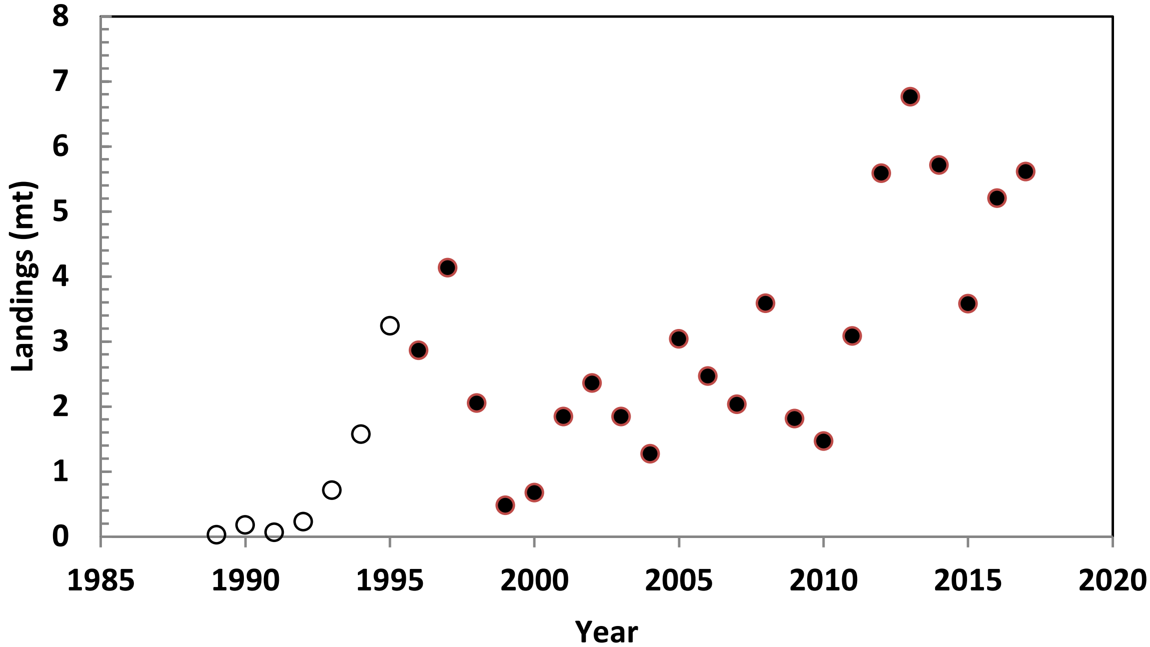


Figure 13. Elver landings (mt) versus time (years). Open and closed circles represent years of experimental and commercial fishing respectively.

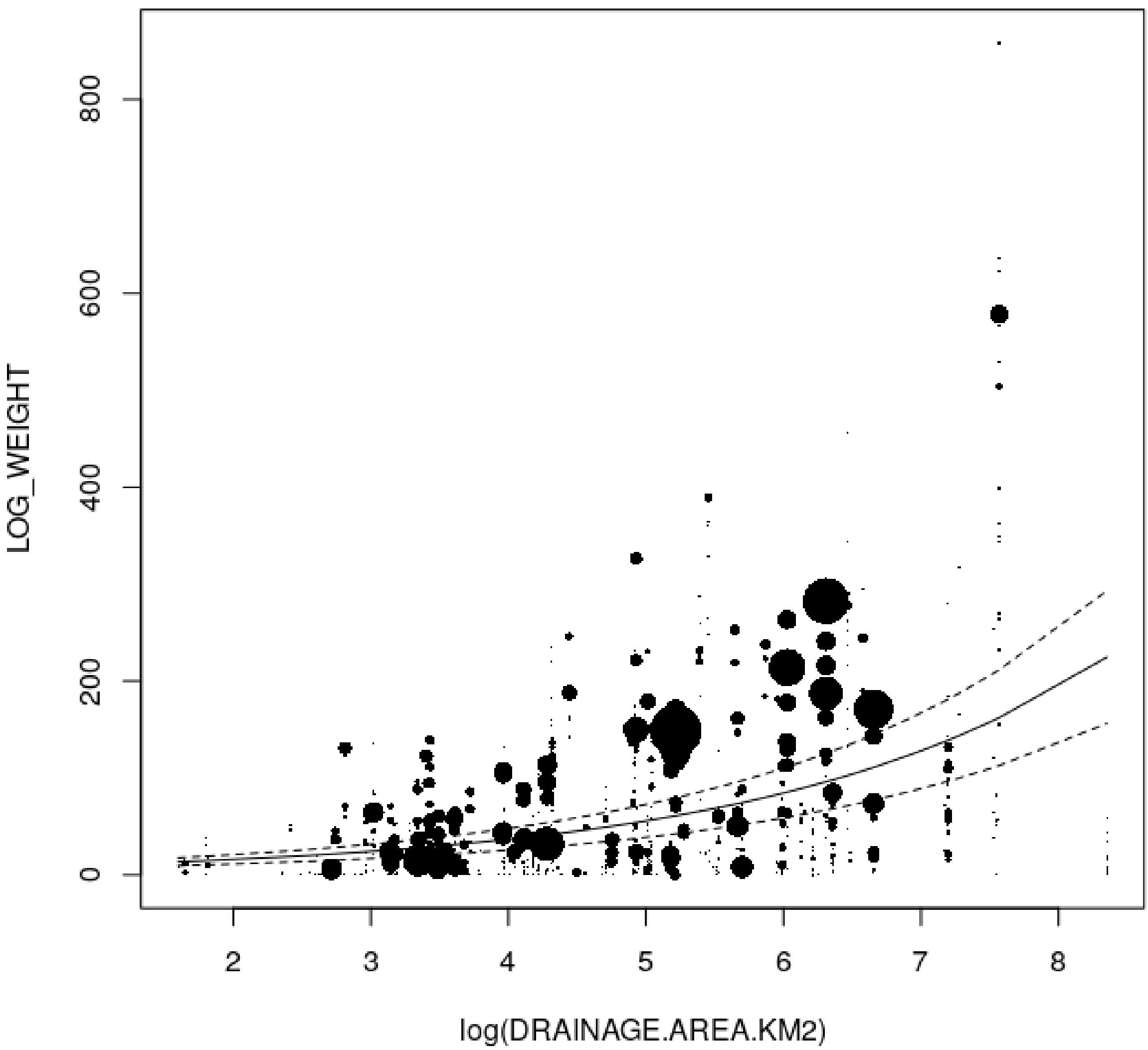


Figure 14. Plot of commercial elver catches (kg wet-weight) versus the log transformed area (km^2) of the fishing locations. Their predicted (solid line) relationship from a Generalized Linear Model (GLM) is shown along with the 95% Confidence Intervals (dashed line). Symbol size portrays the scaled level of effort that was included in the GLM as a weighting factor.

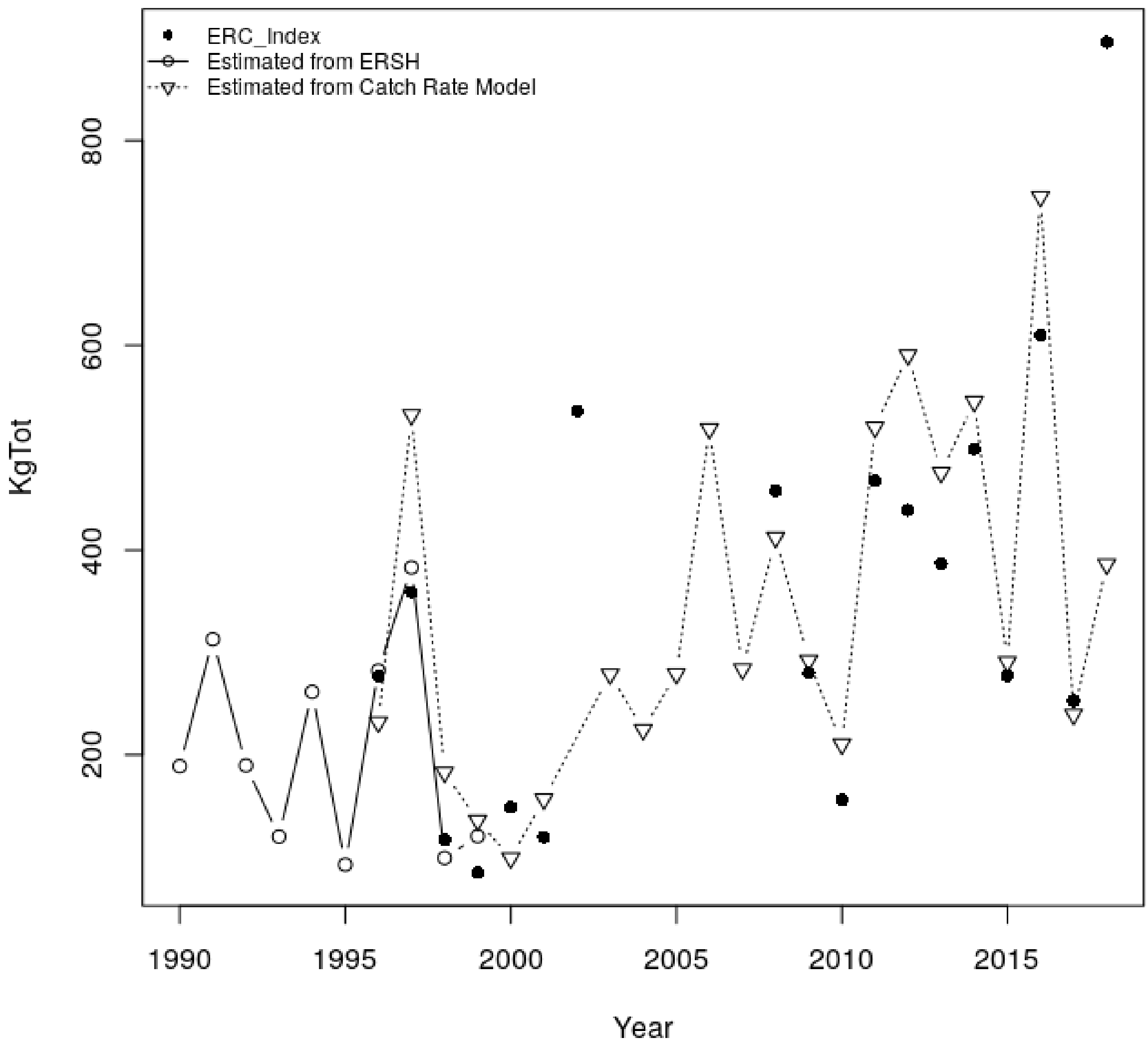


Figure 15. Plot of elver run size (kg wet-weight) to the East River Chester versus year of sampling. Open circles show the predicted values from regression of the East River-Chester run size with East River-Sheet Harbour run size (number of elvers) for the years 1996 to 1999. Closed circles are observed estimates for East River-Chester. Triangles show the predicted values from modelling catch rates for the commercial fishery.

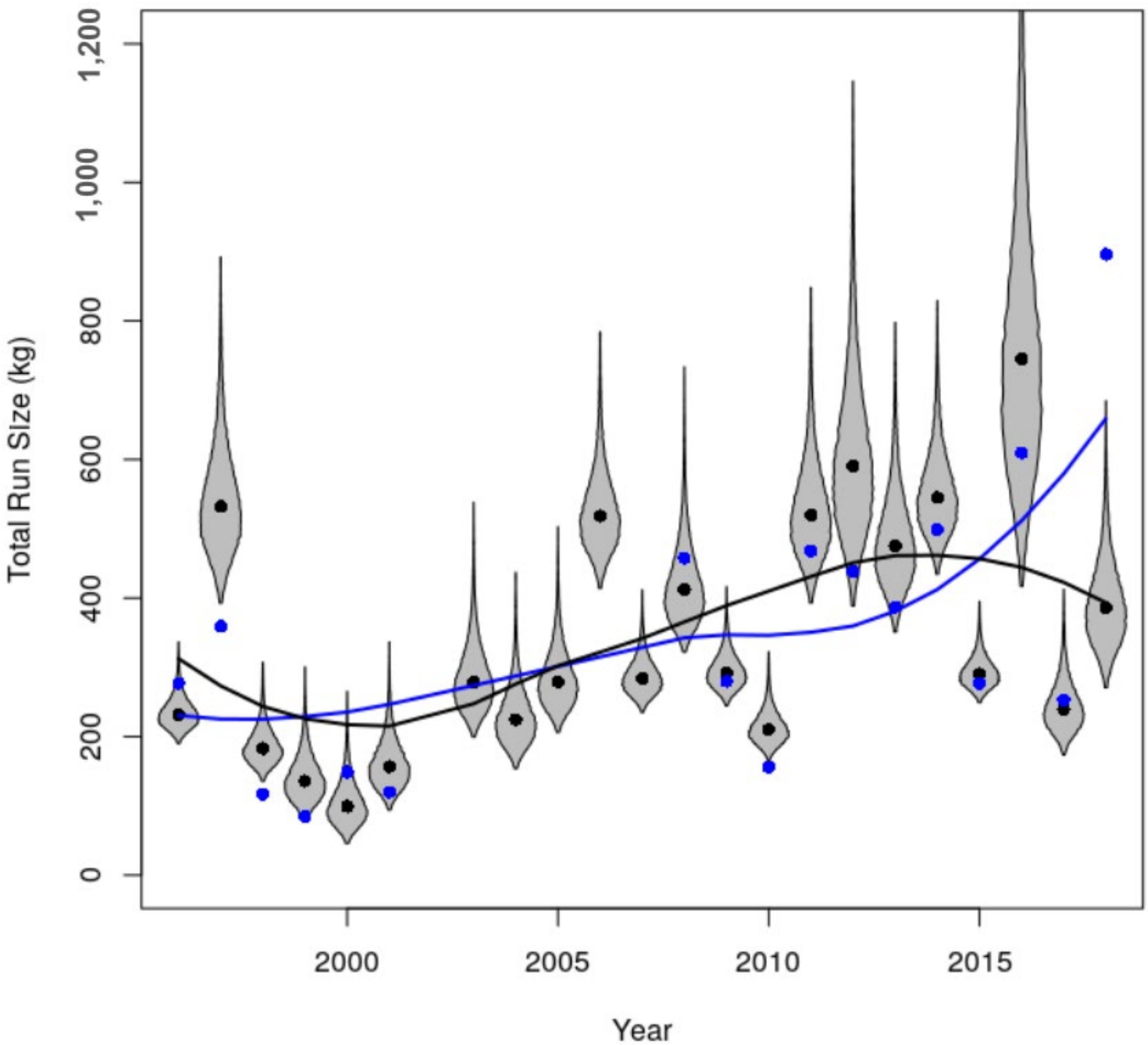


Figure 16. Total elver run size (kg) to East River-Chester by Year. Observed values are shown in blue. Predicted median values from modelling catch rates in the commercial fishery (all rivers fished by the licence combined) are shown as black dots along with violin plots for each predicted value. LOWESS smoothers have been fit to the series with a span of 0.8.

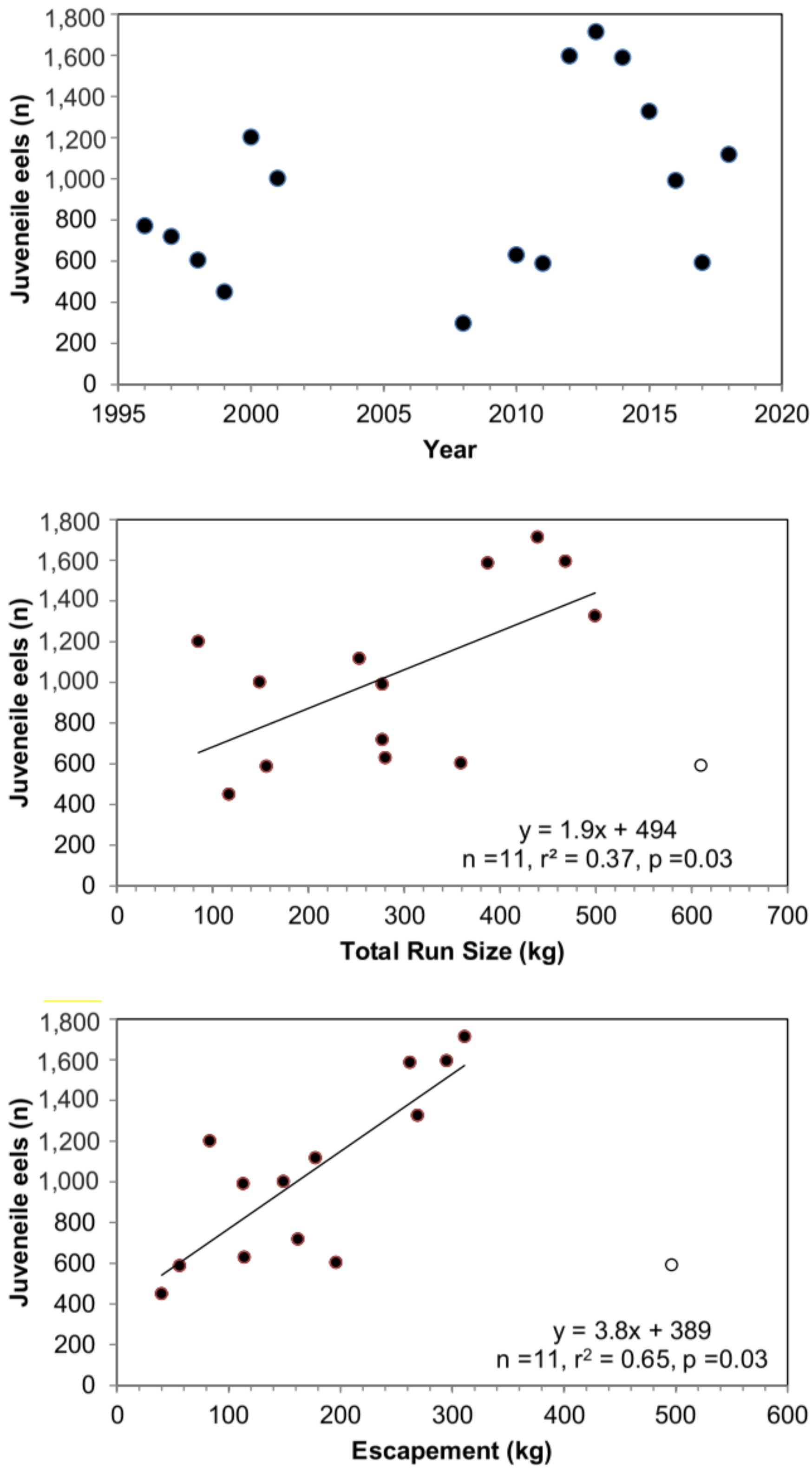


Figure 17. East River-Chester juvenile abundance index versus year of sampling (upper panel), the total elver run size of the previous year (middle panel), and versus the elver escapement of the previous year (lower panel). A partial count obtained during 2017 has been excluded from the regressions shown.

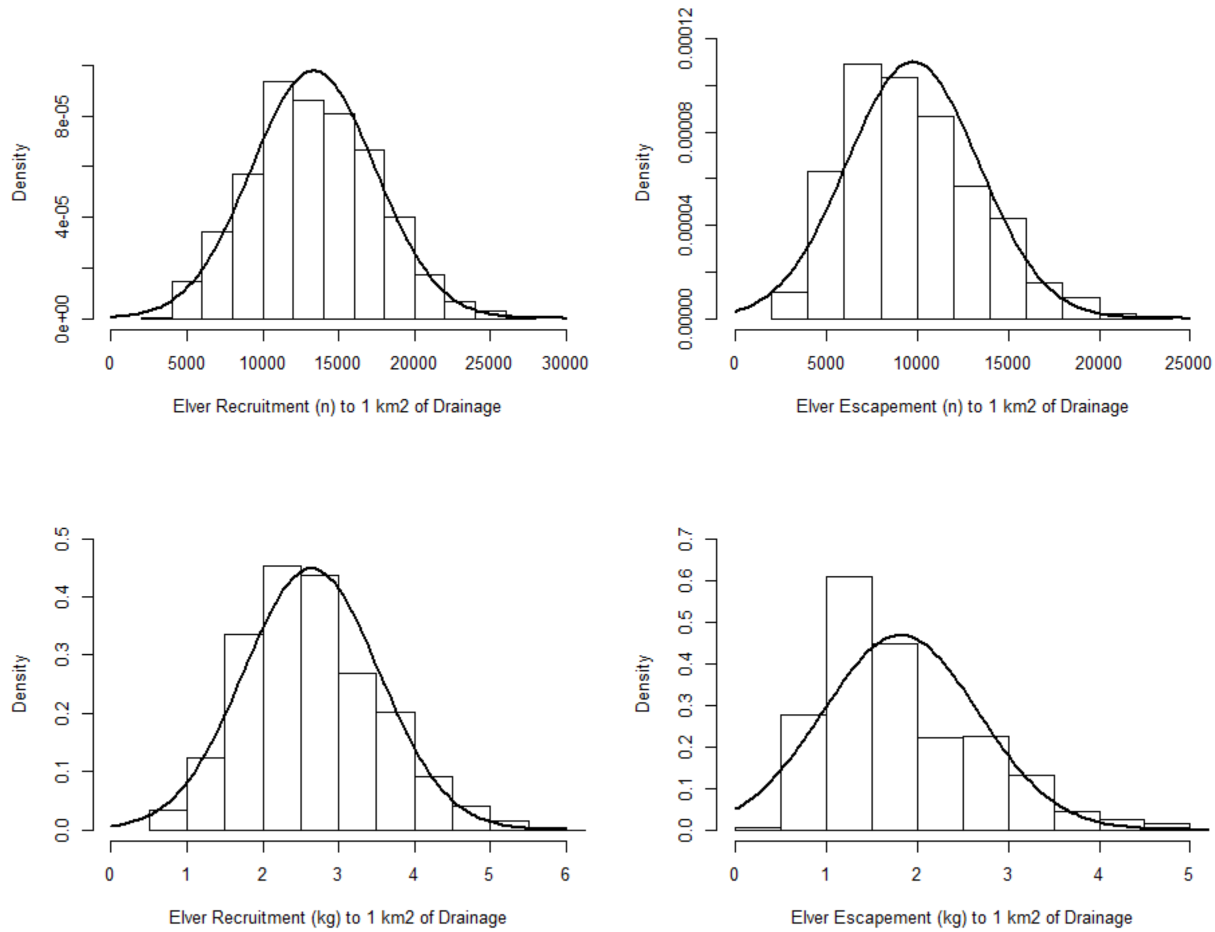


Figure 18. Density distributions for bootstrapped estimates (n = 5000) of elver recruitment (left-hand panels) and elver escapement (right hand panels) to East River Chester (Years 1996–2002, 2008–2018) scaled to 1 km² of drainage area. Upper panels show estimates for number of elvers. Lower panels show estimates for kilograms (wet-weight).

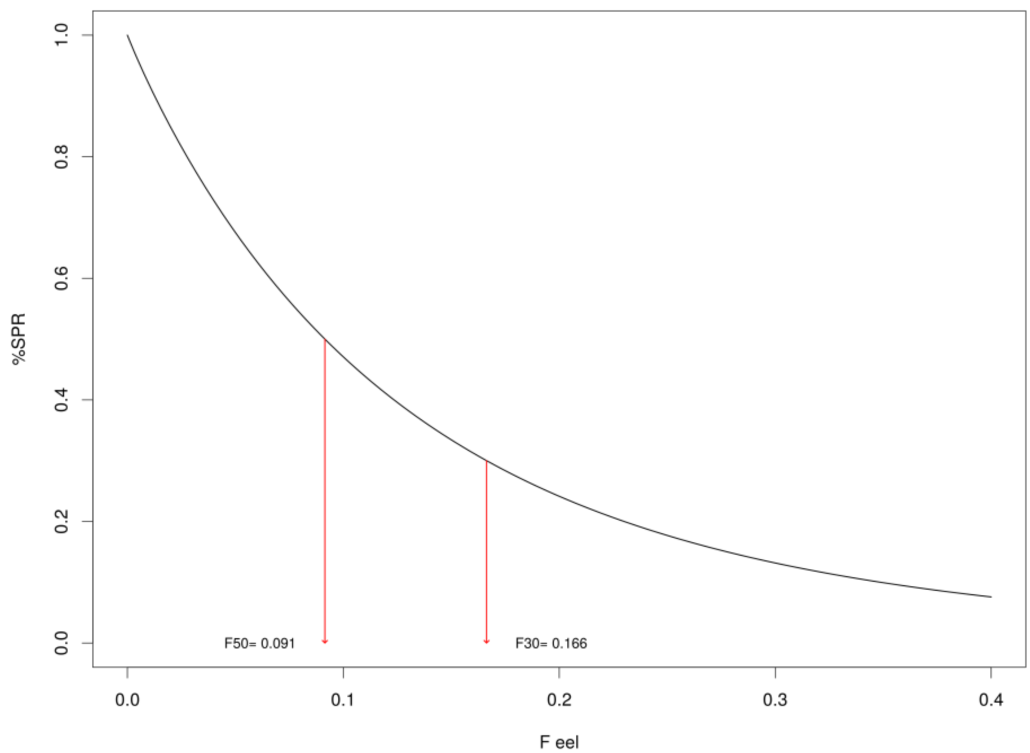


Figure 19. Percent Spawner biomass Per Recruit versus Fishing Mortality (F) for eel fisheries. F at SPR_{30} and SPR_{50} are shown.

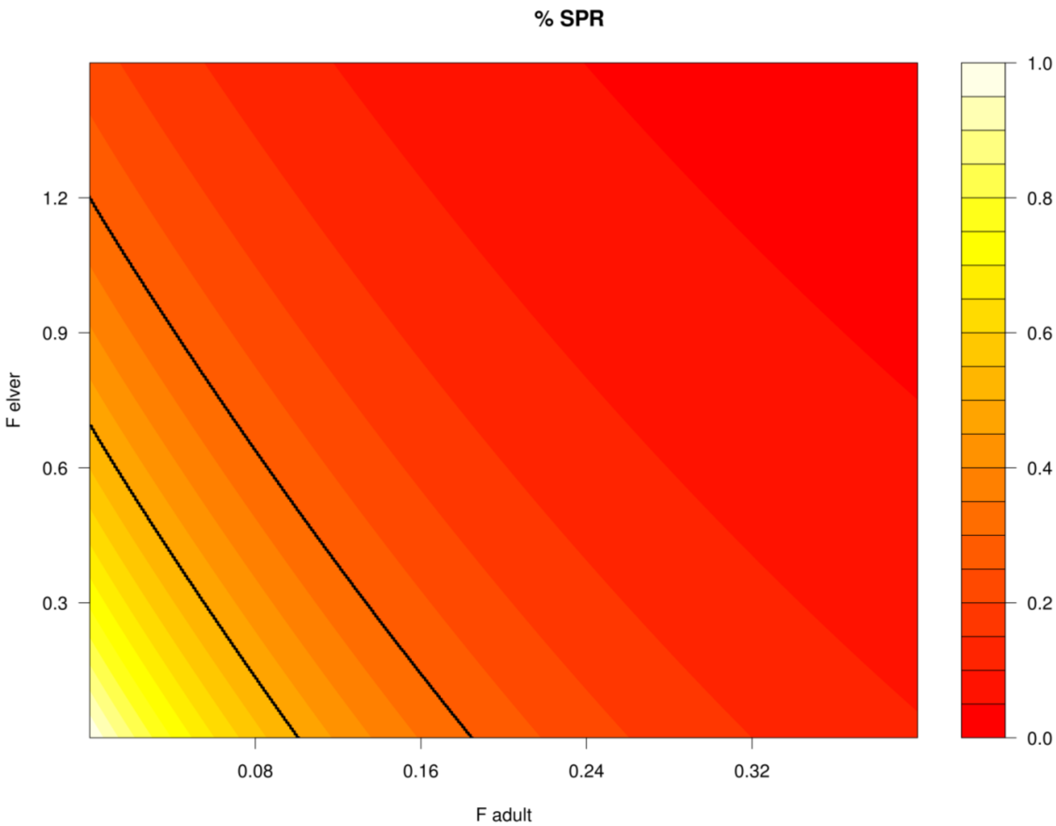


Figure 20. Reference point associated F values for elver fisheries versus F values for eel fisheries when the two fisheries co-occur.

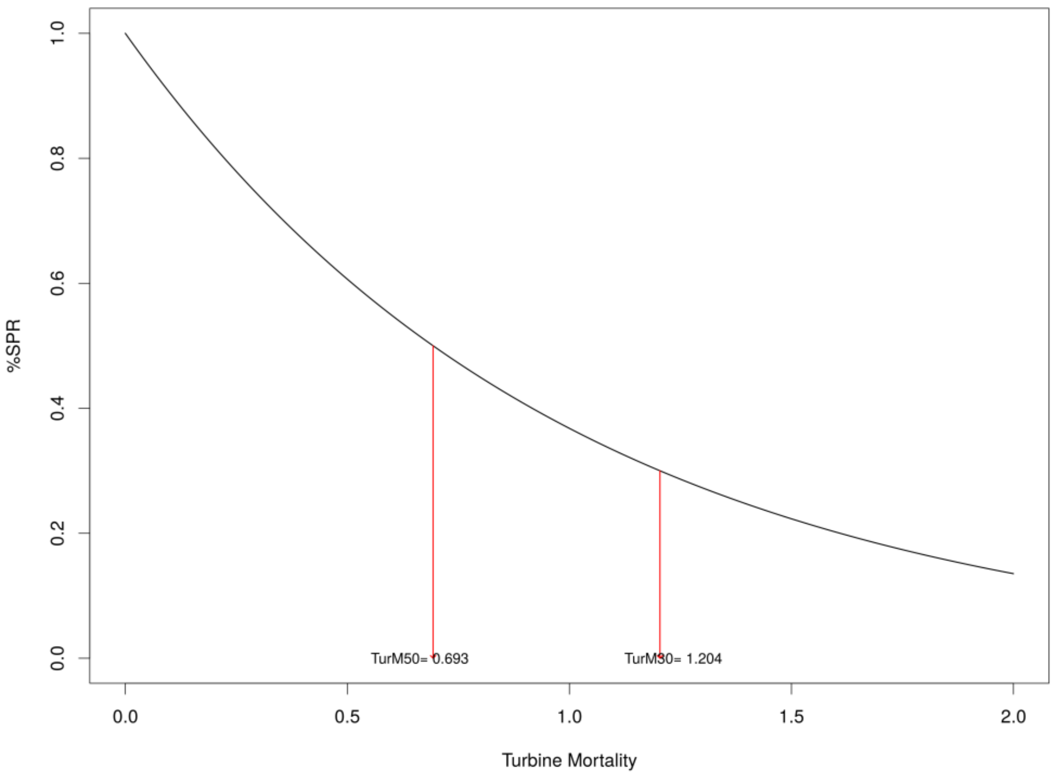


Figure 21. Percent Spawner biomass Per Recruit versus Turbine Mortality (F) at hydroelectric utilities. F at SPR_{30} and SPR_{50} are shown.

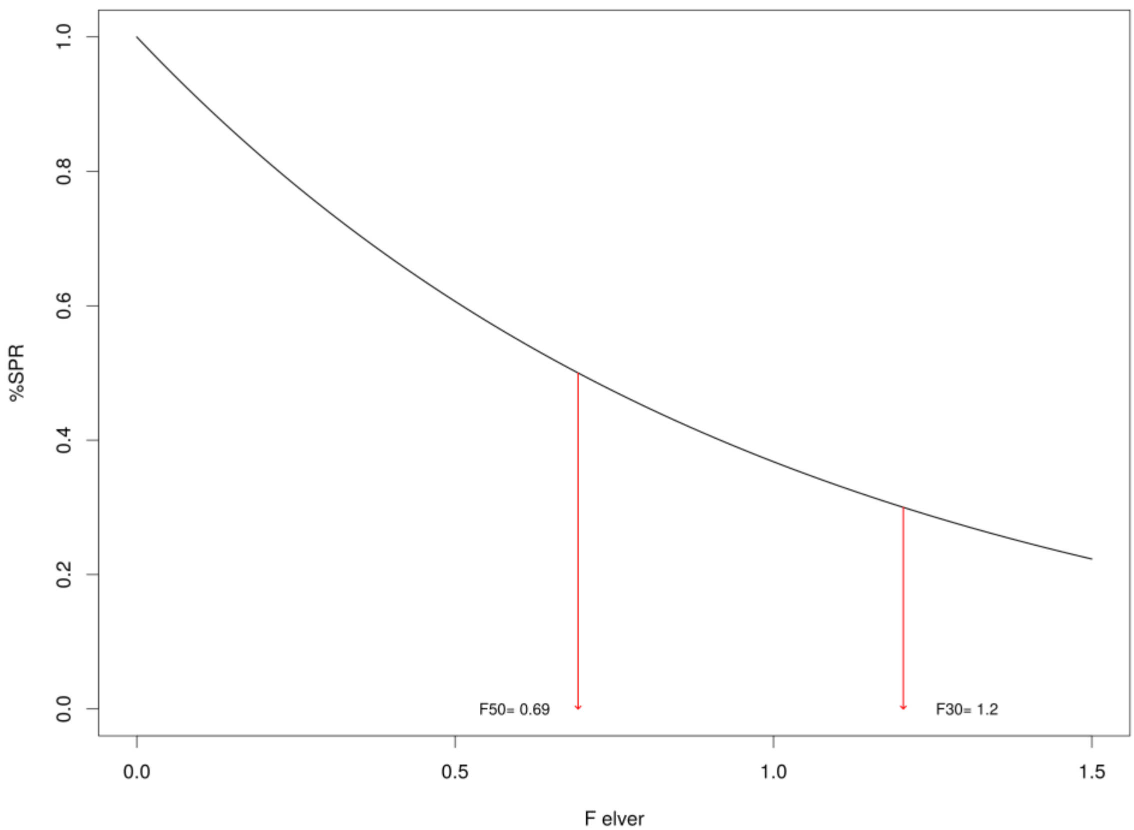


Figure 22. Percent Spawner biomass Per Recruit versus Fishing Mortality (F) for elver fisheries. F at SPR_{30} and SPR_{50} are shown.

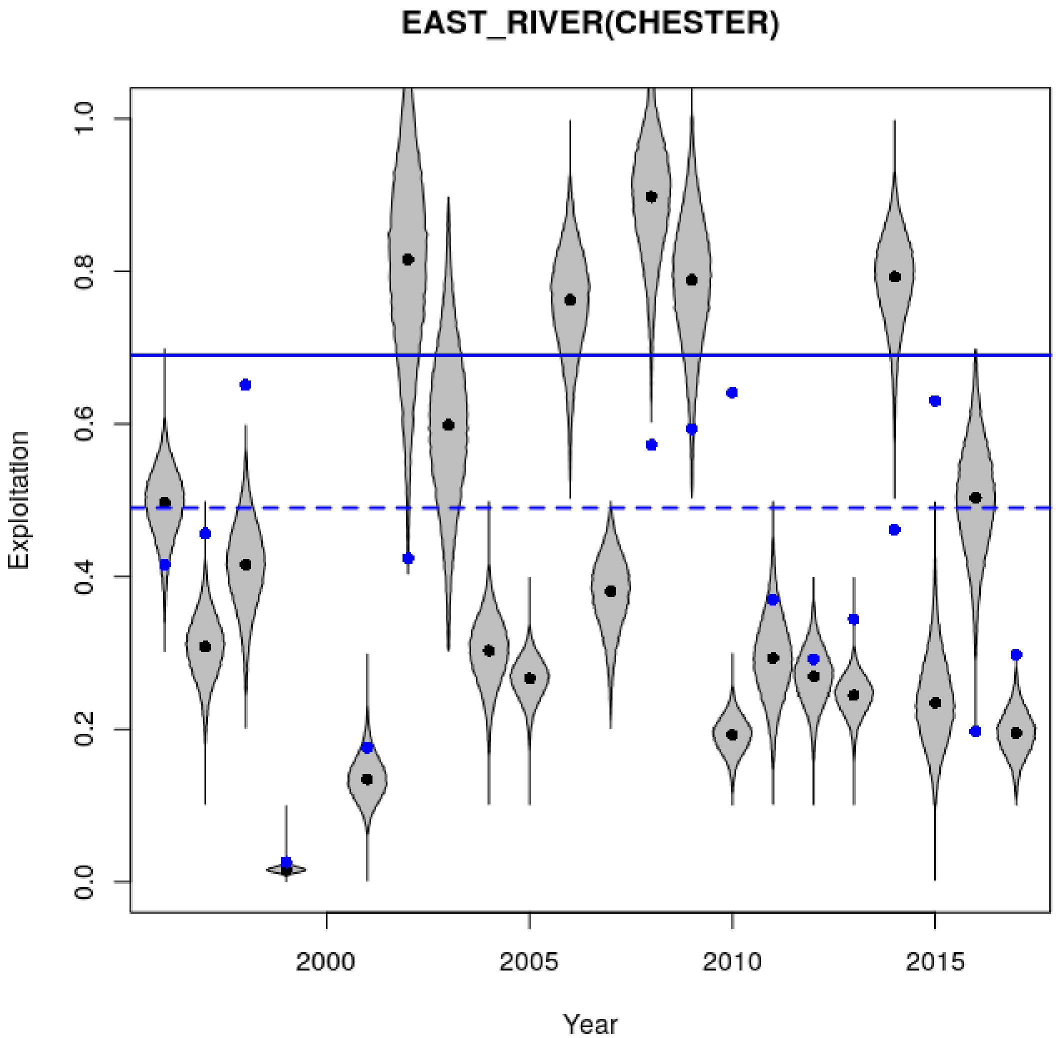


Figure 23. Observed and modelled exploitation rates for the East River-Chester elver fishery relative to exploitation rates corresponding to SPR_{30} (solid line) and SPR_{50} (dashed line).

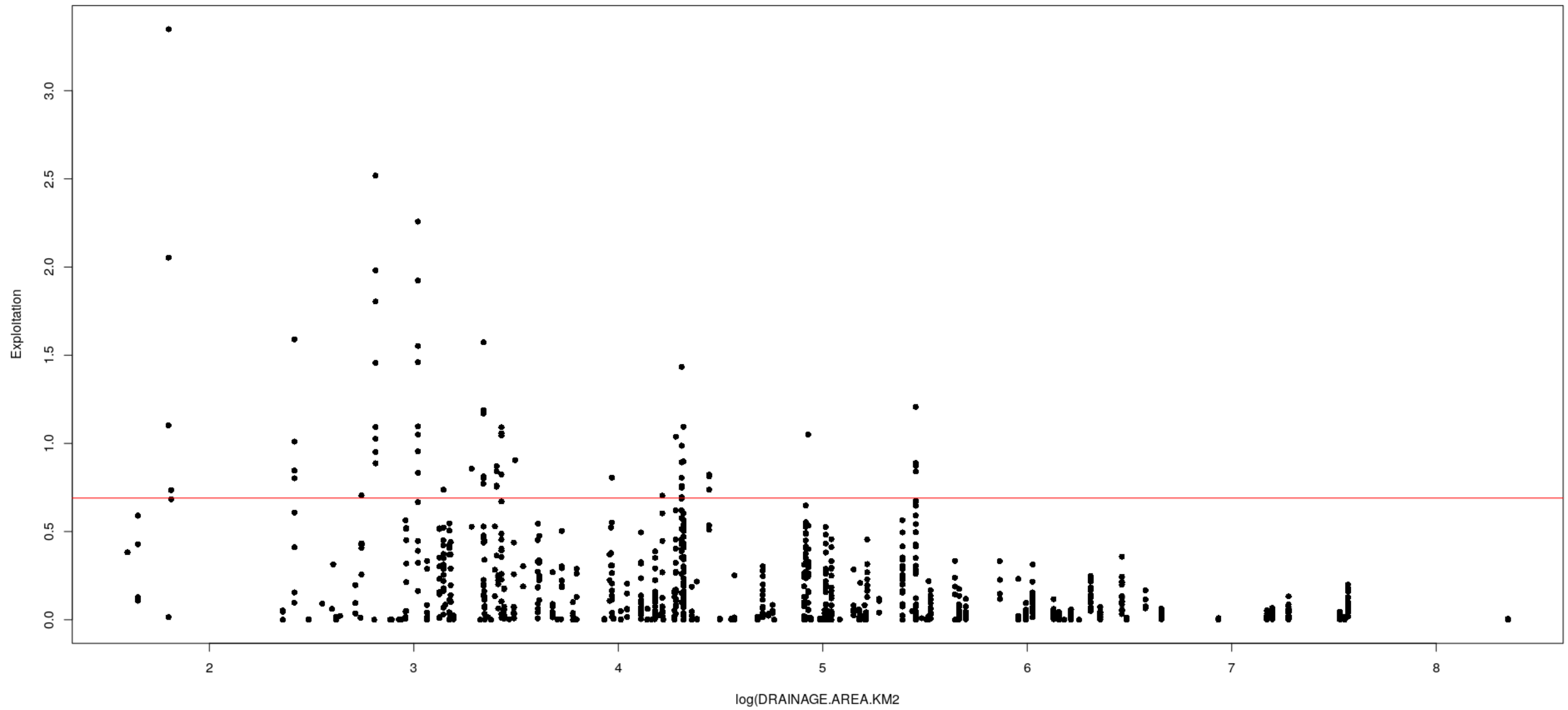


Figure 24. Exploitation rate versus log drainage area (km^2) for the Maritimes Region elver fishery. The fishing mortality(0.69) that corresponds to SPR_{50} is depicted with a solid line.

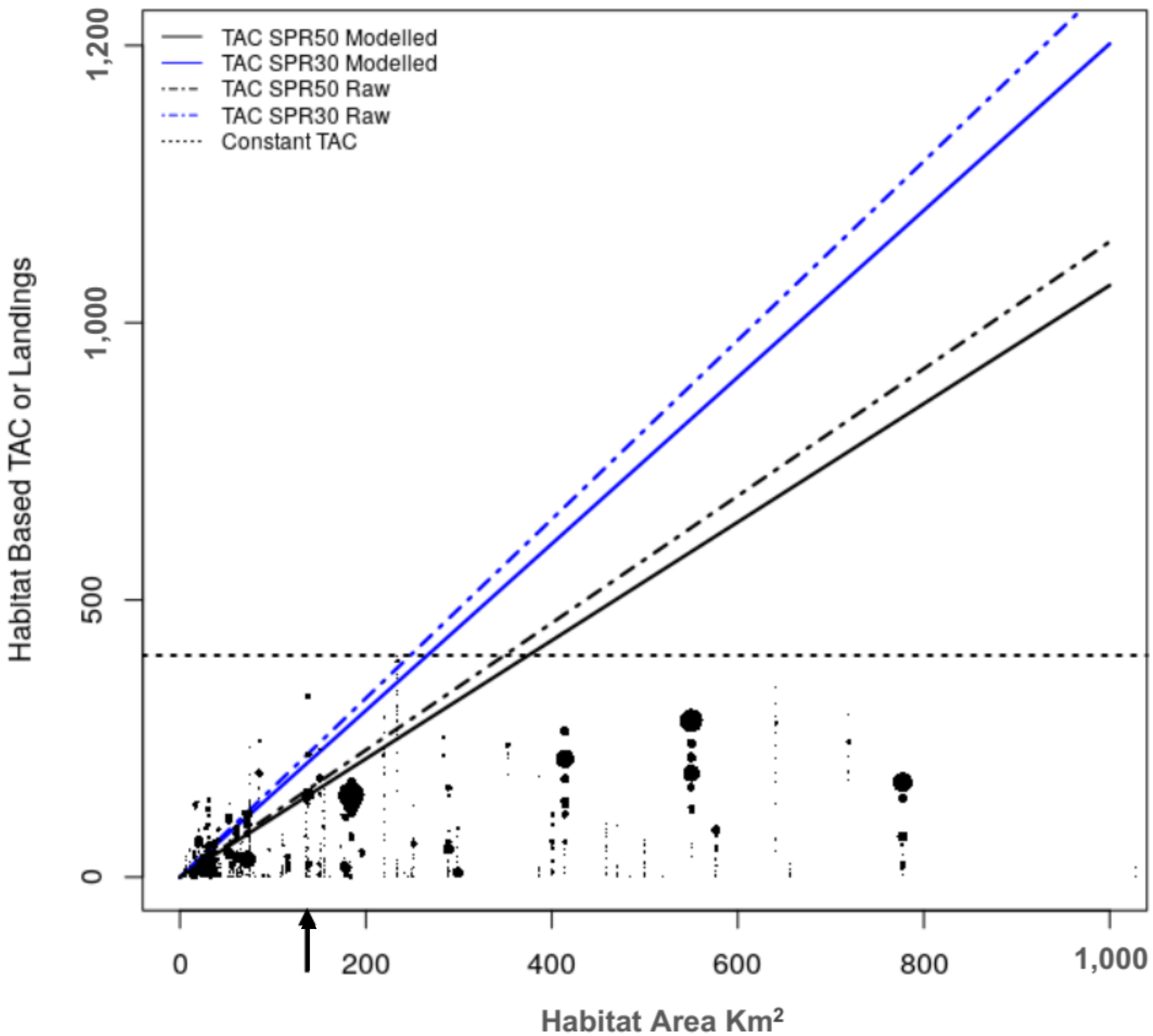


Figure 25. Maritimes Region elver landings (all years combined) scaled to effort versus the drainage area (km²) associated with fishing locations. The horizontal dashed line depicts a constant Total Allowable Catch of 400 kg, the landings associated with SPR_{30} and SPR_{50}, as estimated either from the observed (RAW) or modelled East River-Chester recruitment data, are shown as a function of the drainage area. The arrow below the horizontal axis shows the approximate location of the East River-Chester within the data set.

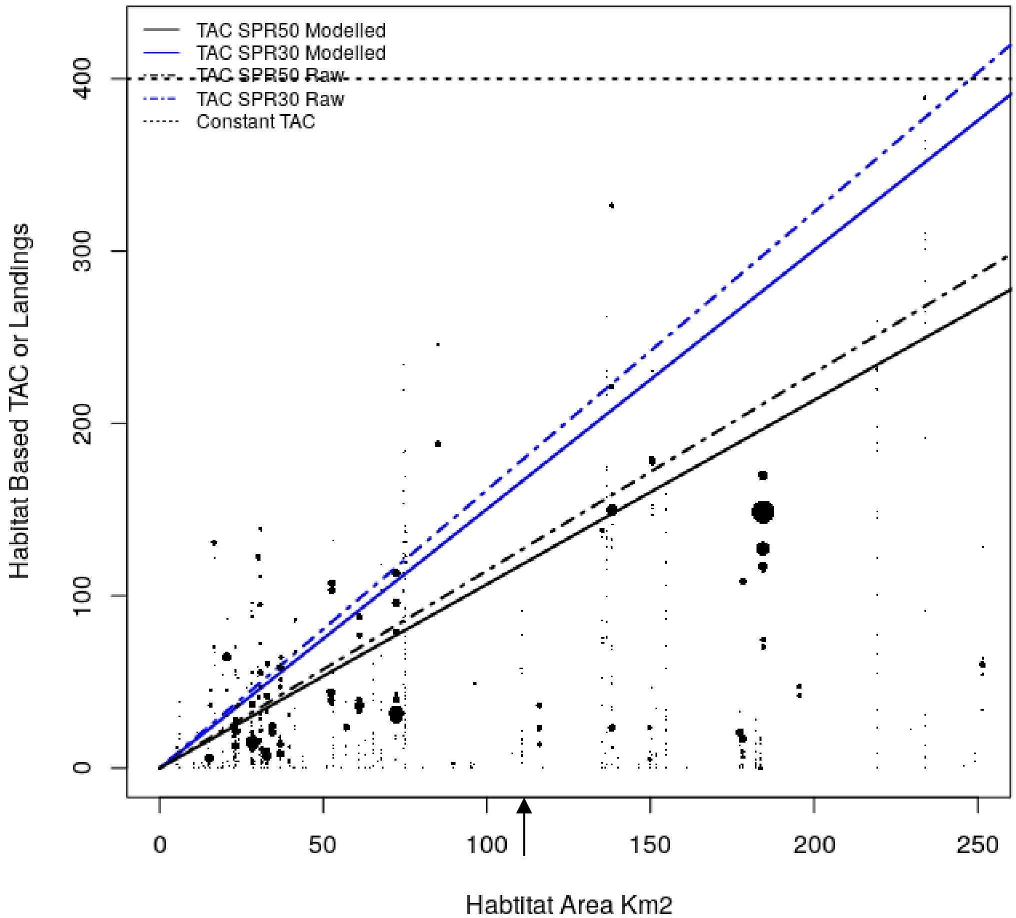


Figure 26. Maritimes Region elver landings (all years combined) scaled to effort versus the drainage area (km^2) associated with fishing locations truncated at 250 km^2. The horizontal dashed line depicts a constant Total Allowable Catch of 400 kg, the landings associated with SPR_{30} and SPR_{50}, as estimated either from the observed (RAW) or modelled East River-Chester recruitment data, are shown as a function of the drainage area. The arrow below the horizontal axis shows the approximate location of the East River-Chester within the data set.

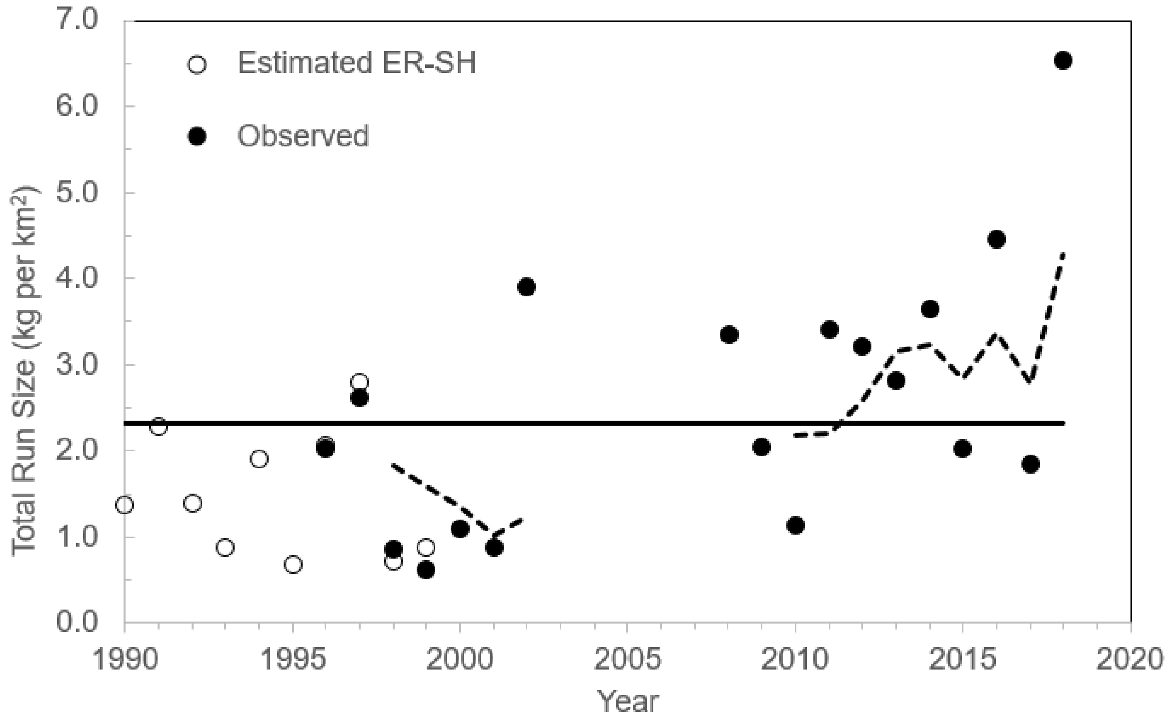


Figure 27. The East River-Chester elver recruitment index, scaled to a per km² area relative to the long-term median run size for the series.

APPENDIX I

ELVER RUN MONITORING TO THE EAST RIVER-CHESTER

Study Area

East River-Chester is located within Mahone Bay, Southwestern Nova Scotia (Figure 9) and lies within the Southern Uplands (SU) area of Nova Scotia (Watt et al. 1983). The river has a catchment (C) area of 134.0 km^2 and two principle tributaries: East Branch (C = 45.5 km^2) and Canaan River (C = 69.4 km^2). The branches join about 4 km above the head of tide (Figure 9). A third, smaller catchment, Barrys Brook (C = 19.1 km^2), joins the main stem about 0.5 km above the head of tide. Lakes and ponds comprise around 11% (1,186 ha) of the catchment area and approximately 95% of the total wetted area (1,250 ha).

The river drops 1 m in elevation over a distance of 11 m at the head of tide. Much of the drop (0.6 m) occurs below a boulder sill located 2–3 m above tidal influence. The drop impedes elver access to the river with the result that they build up at the base of the drop. Facilities are installed downstream of the drop to collect elvers for the purposes of census and biological sampling.

Collections

Four 'Irish style' collection traps (O'Leary 1971) are installed below the sill to collect elvers, two traps on either side of the river (Figure 9). Each trap consists of an elongated covered box that receives attraction water drawn through hoses by gravity feed from above the sill. The downstream end of each box is open and rests on a concrete ramp (one per trap) that extends into the river and below the water surface. Water flow through each box is adjusted as necessary to maintain a wetted surface for elvers to ascend. Each collection box is attached to a holding box by a hose whose opening is near the top of the collection box. A flow of water, also sourced by gravity feed from above the sill, is used to direct elvers to the holding box.

Ideally, the traps are installed prior to the arrival of elvers at the river mouth, but in practice this is rarely possible because the river is frequently in freshet following ice-out in March–April. The dates that the traps became operational have varied from as early as April 15th in 2011 to as late as May 21st in 1997 (Table A1). Commercial fishing activity can precede trap-based monitoring by several days in some years (Table A1). Locations were selected with the objective of collecting all elvers migrating upstream and with the assumption that the water velocities typical of spring/early summer river flows would prevent natural ascent of the sill in significant numbers. Jessop (2003) estimated the proportion of the elver run that escaped capture to be < 0.25%. Trap locations can vary slightly from year to year and whenever previously occupied locations become unsuitable because of deposition of boulders or bank scouring.

Sample processing

Counts

Elver catches in the traps are processed every morning, and again in early evening on days with large catches. Elvers are counted by hand when catches are small (e.g., < 300 elvers) and by volumetric estimation when hand counts become impractical. During the years 1996 to 2002, total catch volume was converted to number of elvers based upon calibrated estimates of the number of elvers per 50, 75, or 100 ml volumes. According to Jessop (2003), other intermediate volumes were sometimes used (Years 1996–2001) and adjusted to the 50 ml volume. In an attempt to compensate for the decline in average elver body size that occurs as the runs progress (Jessop 1998b), elver per unit volume estimates were acquired, usually twice, during the run (Table A1). Calibration methods varied among years, with the elvers from nine or more replicates of various volumes counted twice per season from 1996–2001 (Table A1), to a single calibration consisting of 10 replicates in 2002.

A 100 ml volume was adopted as the calibration standard beginning in 2008 (Table A1). Single estimates of elvers per 100 ml were acquired at least once per week for the years 2008–2010 (Table A1). Multiple daily estimates have been acquired every two to three days (Monday, Wednesday, Friday) over the duration of the annual runs, beginning in 2011 whenever a sufficient number of animals was available (Table A1).

Volumetric-based estimates of elver abundance were discontinued in 2016 in favour of weight-based estimates in order to more directly relate the counts (escapement past the commercial fishery) to catches (removals by the commercial fishery) which are reported as wet-weights (kg). Elver trap catches were weighed (nearest 0.01kg) on site following the weigh-out protocol for commercial licence holders (see below). Three sub-samples of elvers weighing approximately 100 g were acquired. Each sub-sample was counted independently by 2 field technicians with each count recorded separately.

Elvers that were not retained for biological sampling were returned alive to the river about 75 m upstream of the sill.

Biological Traits

Three times per week, usually on Mondays, Wednesdays, and Fridays, during the years 1996 to 2001, a sample of up to 50 elvers, as available, was killed in 4% formalin then immediately measured for total length (TL, to 0.1 mm) with a digital caliper and weighed (to 0.01 g) after blotting dry. Pigmentation stage was assessed according to the criteria of Haro and Krueger (1988). Sample sizes were increased to 100 elvers in 2011 and 4% formalin was replaced with a 10% clove oil solution as the means to immobilize elvers prior to acquiring measures of total length, total weight, and assessment of pigment stage. Elvers were measured to length, but not weighed in 2008 (Table A1).

Juvenile eels (fully pigmented and/or sizes exceeding 75 mm and 0.35 g) were separated from the elvers and counted. Otolith analysis has supported the elver/juvenile designations based upon these criteria (Jessop et al. 2002).

Measurement of juvenile eel lengths and weights was inconsistent among years.

All juveniles were returned alive to the river upstream of the sill.

Details of the elver monitoring-protocols, activities, and outcomes for the years 1996–2000 are contained within internal DFO reports, Jessop1998a and 2000b. Annual reports for the years 2001 and 2002 are not available. Proprietary reports of monitoring activities and outcomes have been maintained by industry since 2008.

Commercial catches

Commercial fishing for elvers on the East River-Chester occurs via dip netting in tidal waters below the Highway 3 river crossing downstream of the elver trap sites (Figure 9). Fishery-related activities begin with a search phase consisting of 15–30 minute visual inspections of the river for presence of elvers. Search methods can vary, from presence of elvers under over-turned stones, to presence of elvers in the water column, to sweeping dip nets through the water. The latter activity is recorded in the commercial fishery logbooks thereby providing an indication of the time of first arrival of elvers to the river mouth for the year (Table A1).

Commercial fishing proceeds on a more-or-less daily basis once commercially viable quantities of elvers are detected. The total allowable annual catch from the East River-Chester is capped at 400 kg wet-weight. Fishing can cease before the river quota is reached when nightly catches are judged insufficient to justify further effort. As well, factors unrelated to elver run strength can influence commercial fishing activity—and therefore inference about elver run status from the fishery—on the East River-Chester. These factors include inter-annual variability in the market-incentive to fish, and the fishing effort directed to East River-Chester relative to the effort directed toward elvers on other rivers the licence holder is authorized to fish. Fishing activity, both on a daily and annual basis, on the East River-Chester can be influenced by fishing success on other rivers. As well, fishing for the year may cease when the global quota for the licence holder has been filled before the river specific limit of 400 kg has been reached. Licence holders may also choose to cease fishing before their quota is met if elver quality, relative to market preferences, has deteriorated over the course of the elver run (Yvonne Carey, Atlantic Elver Ltd, Caledonia, NS, personal communication).

Licence holders are required to maintain detailed logbooks that record the date, number of dip nets (fishers), fishing effort (to 0.25 h, total effort is number of nets x hours), and catch (to 0.1 kg). Catch weights are estimated at stream side, as a condition of licence, prior to transportation to a holding facility. However, it is the weigh-in that occurs at the holding facility, before elvers are placed in holding tanks, that is recorded in logbooks. The weigh-out protocol required as a condition of licence is as follows: elvers in aliquots of approximately 1,200 ml (roughly corresponds to 1 kg of elvers) are placed in a holding basket of known weight and with a screen bottom and allowed to drain for 2 minutes. Excess water is shaken from the basket before being weighed on an electronic balance. The weight of the basket is subtracted from this value to acquire the estimate of catch wet-weight.

A standard conversion of 4,000 elvers per kilogram wet-weight has been applied in past years to estimate number of elvers removed by fishing.

Elver per unit volume calibrations

Elver lengths and elver weights can decline significantly over the duration of annual runs. These changes present a challenge to estimating run-size, in terms of number of elvers, when daily catches are large and hand counts become impractical. Conversion factors (elvers per unit volume) are required to relate elver numbers to catch volume. Summary of the calibrations conducted since 1996 (Table A1) shows that prior to 2008, the number of calibration events was low relative to the duration of annual runs. Both the accuracy and precision of the abundance estimates could vary among years as a result.

The turn-over in field technical support has been significant since the implementation of elver monitoring in 1996. In some years, the turn-over has been complete, with the result that new staff were left to interpret the written sampling (calibration) protocols without reference to how these may have been interpreted in previous years. The potential for observer bias in the estimation of calibration factors therefore exists.

Estimation of elver numbers per volume from biological data

In light of the inconsistencies among years in generating elver per unit volume estimates, the data available for the years 2013, 2014, and 2015 was used to assess whether or not credible estimates of elvers per unit volume (elver volumes) could be generated from the body-size traits (total length [0.1 mm], total weight [0.05 g]) of the elver catches. These years were selected because a relatively large number of elvers/100 ml estimates (3 replicates per sampling date are targeted) and body lengths and weight measurement (n = 100 for each per sampling date) were available (Table A1). Also, the volumetric estimates and body size measurements were acquired on the same day or within 24h of each other. As well, at least some individuals of the field technical staff were present in all three years, thus allowing for some confidence that field measurements have been acquired in a consistent fashion.

Data were first inspected for each year to confirm that elver volume estimates changed with time and that elver lengths and weights changed with time, and inversely with the volumetric estimates. Elver lengths and elver weights less than quantile 0.025, and greater than quantile 0.975 of the length-weight relationship for individual dates of sampling were removed. All elver volume replicates were included in further analyses.

A re-sampling routine was developed to generate pairs of slope and intercept values from linear regression of body size (length, weight) to elver volume (elvers per 100 ml) using the pooled data for the three years. Each data pair represented the mean of 35 lengths or weights and a single elver volume estimate acquired during the same date as the elver body size measurements. All sampling was with replacement. Slope and intercept values lying within their 95% Confidence Intervals were retained and used to generate predicted volumes for individual estimates of mean body size (length, weight).

Table A1. Summary of elver monitoring and commercial fishing activities on East River-Chester for the Years 1996 to 2015. The 1st Visit refers to the dates that the river was visited to initiate commercial fishing activities and that elver index traps became operational. The 1st Catch refers to the date of first elver catch in the commercial fishery and the elver traps. The dates of the last capture of elvers and the last date of commercial fishing or monitoring activities occurred for the year are similarly reported. Duration (Days) refers to the length of time that elvers were available to capture by commercial fishing (Catches) and monitoring (Run). The number of sampling intervals and the total numbers of elvers measured to length and weight are reported under Number of Observations. Events reports the number of days that elvers per unit volume estimates were acquired during the year. Replicates shows the total number of sub-samples acquired.

	1ST Visit		1ST Catch		Last Visit		Last Catch		Duration (Days)		Number of Observations			Calibrations	
Year	Fishing	Index	Fishing	Index	Fishing	Index	Fishing	Index	Catches	Run	Days	Length	Weight	Events	Replicates
1996	27-Apr	04-May	27-Apr	04-May	20-Jun	11-Jul	20-Jun	11-Jul	54	68	28	1,347	1,347	2	18
1997	26-Apr	21-May	11-May	21-May	20-Jun	14-Jul	12-Jun	14-Jul	32	54	23	1,181	1,181	2	18
1998	17-Apr	02-May	24-Apr	02-May	13-Jun	06-Aug	19-May	06-Aug	25	96	33	1,550	1,550	2	18
1999	21-Apr	02-May	24-Apr	03-May	24-Apr	22-Jul	24-Apr	22-Jul	0	80	32	1,446	1,446	2	45
2000	DNF	30-Apr	DNF	01-May	DNF	24-Jul	DNF	24-Jul	DNF	84	34	1,614	1,614	2	54
2001	19-May	06-May	25-May	08-May	06-Jun	18-Jul	27-May	18-Jul	2	71	19	1,132	1,132	2	36
2002	15-Apr	13-May	20-Apr	13-May	28-May	27-Jun	28-May	27-Jun	38	45	10	494	344	1	10
2003	30-Apr	NI	05-May	NI	08-Jun	NI	04-Jun	NI	30	NI	NI	NI	NI	NI	NI
2004	14-Apr	NI	11-May	NI	03-Jun	NI	03-Jun	NI	23	NI	NI	NI	NI	NI	NI
2005	08-Apr	NI	20-Apr	NI	18-May	NI	18-May	NI	28	NI	NI	NI	NI	NI	NI
2006	03-Apr	NI	12-Apr	NI	22-May	NI	19-May	NI	37	NI	NI	NI	NI	NI	NI
2007	26-Apr	NI	04-May	NI	10-Jun	NI	07-Jun	NI	34	NI	NI	NI	NI	NI	NI
2008	09-Apr	30-Apr	19-Apr	04-May	05-May	14-Jun	05-May	14-Jun	16	41	18	867		10	10
2009	10-Apr	30-Apr	27-Apr	01-May	09-Jun	14-Jul	02-Jun	14-Jul	36	74	30	1,401	1,401	6	6
2010	06-Apr	23-Apr	09-Apr	23-Apr	08-Jun	15-Jul	02-Jun	15-Jul	54	83	29	1,444	1,156	9	9
2011	06-Apr	15-Apr	12-Apr	30-Apr	06-May	19-Jun	05-May	19-Jun	23	50	13	1,513	817	12	30
2012	21-Mar	25-Mar	21-Mar	06-Apr	20-Apr	11-Jul	20-Apr	11-Jul	30	96	37	4,388	4,377	26	74
2013	31-Mar	28-Apr	18-Apr	28-Apr	30-Apr	14-Jul	30-Apr	14-Jul	12	77	33	4,049	4,065	18	52
2014	13-Apr	30-Apr	22-Apr	30-Apr	14-May	02-Jul	14-May	02-Jul	22	63	28	2,777	2,777	20	57
2015	04-May	18-May	04-May	18-May	20-Jun	15-Jul	19-Jun	15-Jul	46	58	28	2,778	2,686	10	34
Totals	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**395**	**27,981**	**25,893**	**124**	**471**

DNF = Did Not Fish; NI = No Index