Fisheries and Oceans Canada | Pêches et Océans Canada
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Maritimes Region

Canadian Science Advisory Secretariat
Science Advisory Report 2019/054

ASSESSMENT OF THE MARITIMES REGION AMERICAN EEL AND ELVER FISHERIES

American Eel, Anguilla rostrata (Lesueur 1817). From United States Fish and Wildlife Service (USFWS)

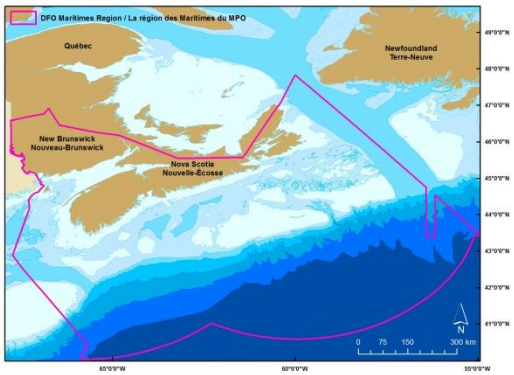

Figure 1. Map of DFO Maritimes Region.

Context:

The American Eel, Anguilla rostrata*, occurs from northern South America to Greenland and Iceland. All are members of a single population, which spawns at sea, migrates to spend a portion of their lives in brackish or freshwater, and reproduces once followed by death. Spawning occurs in the Sargasso Sea well to the south of Canadian territorial waters. Juveniles recruit as elvers to Canadian continental waters in the year following the year of their hatch. In DFO (Fisheries and Oceans Canada) Maritimes Region (Figure 1), American Eel occur in nearly all accessible fresh, brackish and protected coastal waters. They have historically been fished by Indigenous peoples for Food, Social, and Ceremonial purposes, and these fisheries remain culturally important. American Eel are also fished for commercial and recreational purposes throughout the Region. The DFO Maritimes Region elver fishery is the largest in Canada. All removals by fisheries occur pre-spawning.*

In support of the management of American Eel and elver fisheries, DFO Maritimes Fisheries Management has asked DFO Science for an assessment of resource status and the consequences of various harvest levels and strategies. The fisheries were last assessed in 1996 (Jessop 1996a,b). General status of DFO Maritimes Region eels was last assessed in 2010 (Bradford 2013). The status of American Eel in Canada was assessed as Threatened by COSEWIC (COSEWIC 2012) and a Recovery Potential Assessment was completed by DFO in 2013 (DFO 2014). The Recovery Potential Assessment (DFO 2014) identified hydroelectric turbines, habitat loss and fishing of adults as the principal threats to spawners.

This Science Advisory Report is from the September 5-6, 2018 Assessment of American Eel in the Maritimes Region. Additional publications from this meeting will posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Stock status is not specifically addressed in this assessment because of deficiencies in the reporting of catch and effort in eel fisheries prior to 2016 and because key fisheries-independent indices of standing stock are not expected to be updated until 2019 or later.

- The 2015 and 2016 commercial large eel fisheries were smaller than those of previous decades in terms the number of available licences, the amounts of gear under licence, and in both the number of active participants and amounts of gear associated with active licences. Total commercial landings for the 2015 (36.1 t) and 2016 (44.1 t) eel fisheries were lower by a factor of about four than the 1993 to 2004 average.
- Commercial eel fishing occurred in 47% of the 93,718 km^2 of available habitat (AH) in DFO Maritimes Region in 2015, and 43% in 2016. Eels were fished within 5.6% of the total AH, 5.25% of the drainage area under hydroelectric development, and within 92% (2015) and 86% (2016) of the estimated 38,032 km^2 of the total AH of habitat known to contain the swimbladder parasite *Anguillicoloides crassus*.
- The presently inaccessible 17,014 km^2 area of the Saint John River drainage lying above the Mactaquac Dam and below Grand Falls represents approximately 18% of the habitat historically available to the American Eel.
- The management strategy of limiting elver fisheries to rivers that have not been fished for large eels within any of the three prior years has limited the extent of overlap between the two fishery sectors to <10% of the habitat available to eels.
- The number of rivers where authorized elver fishing activities can take place increased from 65 in 1996 to 111 by 2004, and has been frozen at that number since 2004. Elver fisheries occurred in 92 (28.5% AH), 86 (27.4% AH), and 83 (27.5% AH) rivers during 2015, 2016, and 2017, respectively. The fishery footprint of directed elver fishing is modest at the regional level.
- Total annual landings in the commercial elver fishery exhibited an overall increase with time, with the five biggest years occurring in the last six years of the time series that ends in 2017. The annual Total Allowable Catch was not achieved in any fishing year.
- The potential exists for the area subjected to directed fishing on American Eel to increase with time, either through greater participation in the eel fishery or exchange of rivers presently fished for elvers for those that are larger in drainage area.
- Continuing to minimize the spatial overlap between eel and elver fisheries is an appropriate interim conservation measure until sufficient data is acquired to assess the extent of the cumulative mortality associated with fisheries at multiple life stages.
- Currently, one fishery-independent elver abundance index is available, from the East River-Chester. Elver run size exhibited high inter-annual variability with runs during adjacent years differing by 50% or more in some years. On average, elver runs to the East River-Chester have increased since 1990.
- Spawner per Recruit (SPR) analyses were used to define mortality reference points for all directed fisheries and hydroelectric facilities. The mortality rate that results in a 70% loss of spawning biomass relative to the population without losses from human activities (SPR30), was recommended as the limit removal reference (i.e., the maximum acceptable human-induced mortality rate). The mortality rate that results in a 50% loss of spawning biomass would be the target value (SPR50).
- The SPR analyses applied to the assumed average life-history traits of Maritimes Region eel populations give fishing mortalities (F) corresponding to SPR30 and SPR50 of 0.166 and 0.09, respectively, considering mortality from large eel fishing only.

- Mortality reference points corresponding to SPR30 and SPR50 for eels for a single downstream pass through a hydroelectric facility were F = 1.204 and F = 0.693, respectively, considering turbine mortality only.
- The fishing mortality rates for elver fisheries corresponding to SPR30 and SPR50 are 1.2 and 0.69, respectively (equal to exploitation rates of 0.70 and 0.50), considering mortality from elver fishing only.
- The assessment of current mortality relative to reference points is limited to the elver fishery because of data limitations concerning eel harvests, eel biomass, and adult eel survival following downstream transit through hydroelectric facilities.
- Direct evaluation of elver escapement past the localized East River-Chester elver fishery (years 1996-2002, 2008-2018) estimated that annual removals by elver fishing represented between 5% and 65% of the total elver run to the river. These removal rates are below the limit exploitation rate of 0.69 in all years but were above the target exploitation rate of 0.49 in 5 out of 17 years.
- Under the assumption that elver recruitment across all fished watersheds and years has been at a level equal to the median observed values for East River-Chester, the existing river-specific elver fishery quotas have in some cases exceeded either the target fishing rate at SPR50 or the maximum acceptable fishing rate defined by SPR30. The potential for over-fishing to occur appears to be highest on rivers ≤250 km^2 in drainage area. It may be possible to set river-specific quotas that will vary with the watershed area using an estimate of elver abundance from the single monitored site, East River-Chester, as a guide.
- The running median abundance for the East River-Chester elver recruitment index is recommended as the principle indicator of status. For stock status updates, the 3-year running mean of elver recruitment at East River-Chester would be compared to the median value over the 1996 to 2018 times series. A re-assessment earlier than the proposed 5-year assessment schedule may be warranted if the 3-year running mean of the elver recruitment index for East River-Chester falls below 2.33 kg/km^2.

BACKGROUND

American Eel (*Anguilla rostrata*) are fished at the elver (recruiting), yellow (rearing) and silver (adult) stages in DFO Maritimes Region (Figure 1). Elvers, defined in regulations as eels less than 10 cm in total length, are managed through an Integrated Fisheries Management Plan (IFMP) (DFO 2018) as a distinct fishery. Directed fisheries for yellow eel and silver eel, referred to as ‘large eels’ or simply ‘eels’, occur for Food, Social and Ceremonial (FSC), commercial, communal commercial, and recreational purposes. An IFMP has not been developed for the eel fishery.

A framework review (DFO 2017) evaluated the usefulness of existing data sets as a means to assess the impacts of directed fisheries and hydroelectric generating facilities on American Eel status; for monitoring the spread of *Anguillicoloides crassus,* an invasive swim bladder parasite (Aieta and Oliveira 2009, Campbell et al. 2013) as an emergent potential threat; and for development of fishing mortality-based reference points.

The framework review (DFO 2017) showed that the ability to detect trends over time in large eel catch and effort was limited by availability of detailed fishing records, but in combination with licencing information, changes in reported landings with time could be examined in the context of participation rates and fishery potential (gear types and amounts under licence). Elver fishery

landings and fishing locations have been well documented in logbooks since the inception of the commercial fishery in 1996, but daily catch and effort records were of limited scientific use because site-specific daily catches were frequently reported as the total acquired from fishing multiple gear types simultaneously. Annual estimates of elver recruitment and escapement were available for the years 1996-2002 and 2008-2018 for the East River-Chester (Lunenberg County, NS) as a result of directed monitoring of elver runs to the river. Evaluation of the geographic footprint of (annual) eel and elver fisheries, hydroelectric generation, and the proportion of the resident eel populations potentially infected by *A. crassus*, was possible through use of drainage area estimates for the watersheds where these activities occurred (DFO 2017) and relative to both the 93,718 km^2 of available habitat (AH) currently accessible and the 110,732 km^2 historically available prior to construction in 1968 of the Mactaquac Dam across the Saint John River. Although the available life-history data for freshwater-resident eel populations is limited, mortality-based reference points via Spawner per Recruit (SPR) analysis (Mace and Sissenwine 1993) can be provided for both the large eel and elver fisheries and for out-migrating adult escapement past hydroelectric dams.

The assessment of current human-induced mortality relative to reference points is limited to the elver fishery. Mortality relative to reference points could not be assessed for large eel fisheries or for large eel mortality following downstream transit through hydroelectric facilities because of data limitations.

The purpose of this assessment is to develop advice to management using the assessment approach discussed in the framework review (DFO 2017), 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.

ASSESSMENT

Trends in stock status and exploitation

Terms of Reference (ToR) 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?

Stock status is not specifically addressed in this assessment because of deficiencies in the reporting of catch and effort in eel fisheries prior to 2016 and because key fisheries-independent indices of standing stock are not expected to be updated until 2019 or later.

Information concerning eel fishing activities in the most recent fishing year should not be considered to be comprehensive because some eel fishers wait until close to the start of the fishing season to submit their logbooks for the previous fishing season to a Dockside Monitoring Company (DMC) for data entry. The resultant lag of about one year in compilation of commercial eel catches means that the extent of spatial overlap of eel and elver fisheries will not be known for the most recent year of fishing.

Fisheries dependent data sources

Eel Licences

The 2015 and 2016 commercial large eel fisheries were smaller than those of previous decades in terms of the number of available licences, the amounts of gear under licence, and in both the number of active participants and amounts of gear associated with active licences. In total, 409 licences were issued to fish eels during 2016 (versus 427 in 2015), of which 295 were

commercial, 100 were recreational and 14 were commercial communal (issued to Indigenous communities). Valid licences for Nova Scotia (NS) inland and tidal waters exceeded those for New Brunswick (NB) by a factor of about 10 for all fishing sectors. In 2016, 67% of NB fishers submitted their logbooks to a DMC for data entry whereas the reporting rate for the NS licences was approximately 50%.

The percentage of commercial licences actively fished in NB was 30% (n = 8 of 27) in 2016, whereas only about 11% (n = 30 of 266) of the licences issued in NS were active. Overall, participation rates in the commercial eel fishery were 12% in 2015 and 13% in 2016.

More than 25,000 pieces of gear were authorized to fish for eels in 2016, 90% of which were eel pots, followed by traps (fyke nets, approximately 2,300), and a small number of weirs (27). Eels can be fished recreationally with baited pots and spears and via angling. Gear licenced for commercial fishing accounts for 93% of the total amount of gear under licence. Authorized gear for the commercial licences actively fished represented approximately 12% of the total gear authorized for commercial eel fishing in both years.

The overall 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: 31,752 pots, 2,819 fyke nets, and 45 weirs). The number of active licences in 2015 (n = 36) and 2016 (n = 38) were lower than for the years 1993 to 2014 (mean = 131).

Elver Licences

The number of commercial licences available to fish elvers (n = 9) has remained unchanged since 1998.

Eel Landings

Total landings from FSC fisheries by Indigenous groups were not available as reporting requirements vary for these licences. Recreational eel fishers are not required to report their catch, so these fisheries are not included in reported landings or spatial analyses included in this section. No landings were reported from communal commercial licences for large eels.

Total commercial landings for the 2015 (36.1 t) and 2016 (44.1 t) eel fisheries (Figure 2) were lower by a factor of about 4 than the 1993 to 2004 average (Mean ± Standard Deviation [SD]: 164 ± 44 t). The Saint John River fishery (13 t, 2015; 23.5 t, 2016) accounted for virtually all of the NB landings in both years and 36% and 53% of the total landings for the DFO Maritimes Region eel fishery in 2015 and 2016, respectively.

The relative influence of eel availability versus other factors, such as market incentives to fish or the exchange of eel licences for green crab licences, on reduced landings in recent years is not known.

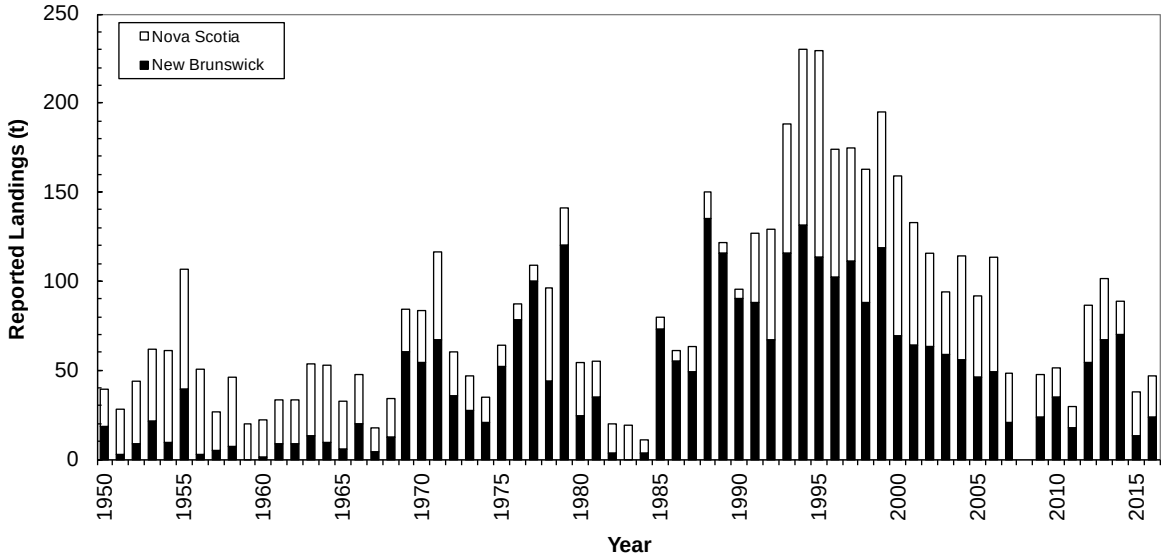

Figure 2. Reported landings (t) for the DFO Maritimes Region commercial eel fishery by Province for the years 1950 to 2016.

Elver Landings

Landings from the elver fisheries have generally increased with time (Figure 3), with landings being generally higher following the transition to a commercial fishery that began in 1996, following an exploratory fishery that occurred during the years 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 that ends in 2017. The annual Total Allowable Catch (TAC; 11.06 t from 1998-2004; 9.96 t from 2005-present) was not achieved in any fishing year.

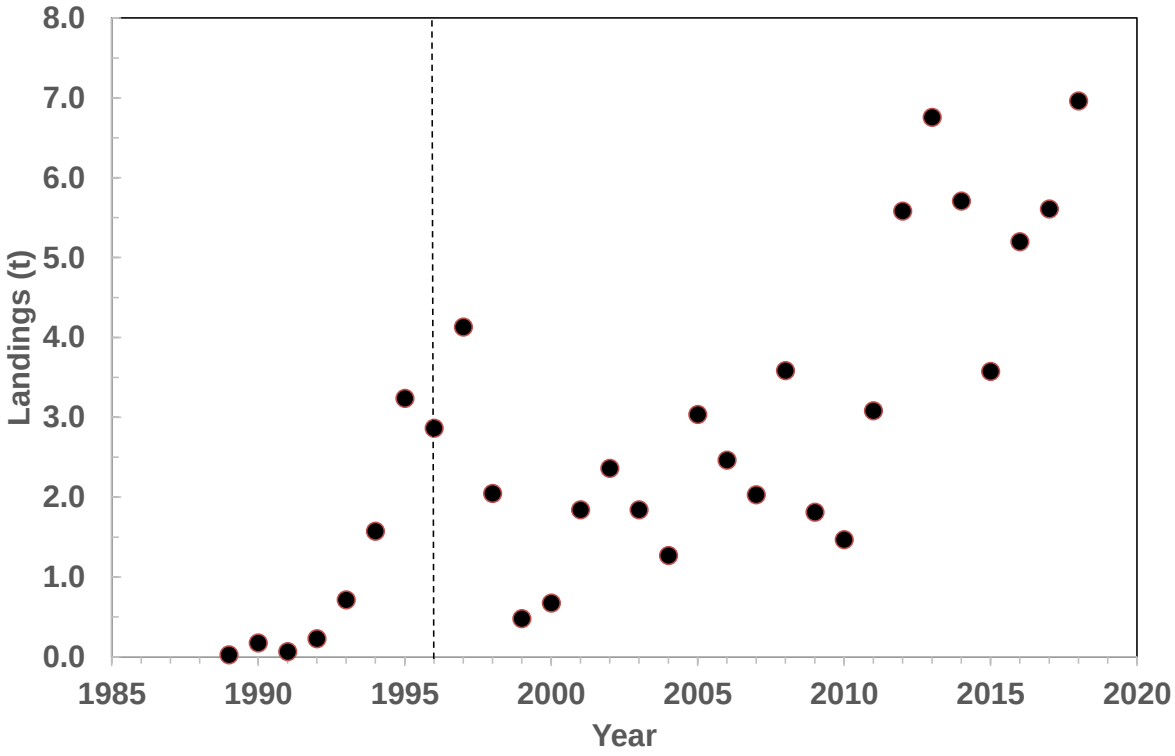

Figure 3. Elver landings (t) by year. The vertical dashed line identifies the year (1996) that transition from an experimental to a commercial fishery began.

Elver catches[1] (kg) fitted with a Generalized Linear Model (GLM), adjusted for effort, to the log-transformed drainage area (km^2) of fishing locations exhibited a positive increase with area, indicating that higher catches occur on larger rivers (Figure 4).

[1] Live elver weights can be significantly increased by adhered water. All elver weights are expressed as "wet weights", which is determined by scooping the elvers out of water in a mesh bottomed container, and allowing the water to drain for not more than two minutes.

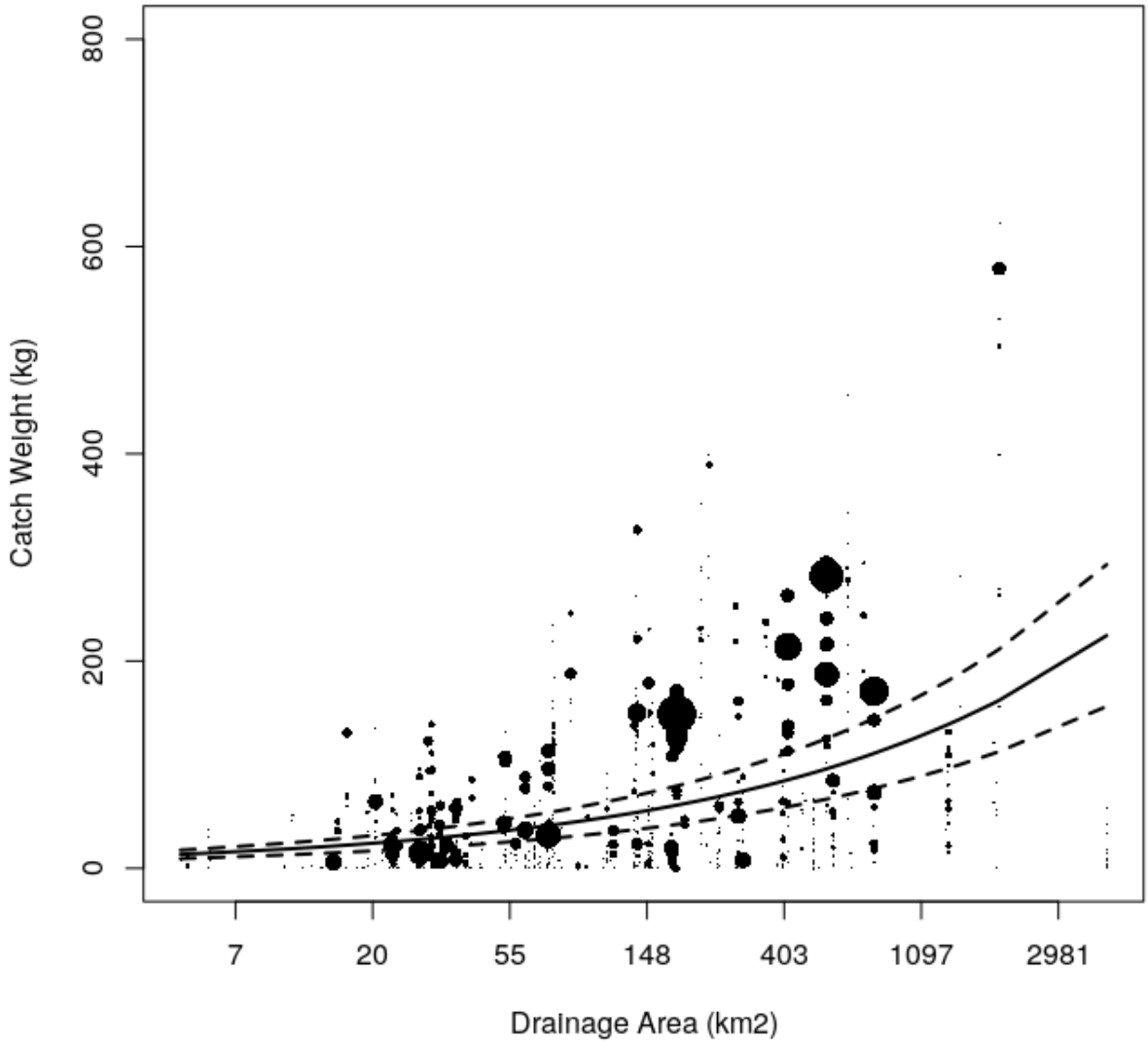

Figure 4. Plot of commercial elver catches (kg) versus drainage area (km^2) of fishing locations (shown on log scale). Their predicted (solid line) relationship from a Generalized Linear Model (GLM) is shown, along with the 95% Confidence Intervals (dashed line). Symbol size represents the level of effort that was included in the GLM as a weighting factor.

Spatial Analysis

Commercial eel fishing occurred in 47% of the 93,718 km^2 of available habitat (AH) in DFO Maritimes Region in 2015, and 43% in 2016 (Table 1). The 29,983 km^2 (32% AH) area of the Saint John River lying below the Mactaquac Dam accounted for 68% in 2015 and 74% in 2016 of the watershed areas in which eel fisheries occurred. The presently inaccessible 17,014 km^2 area of the Saint John River drainage lying above the Mactaquac Dam and below Grand Falls represents approximately 18% of the habitat historically available to the American Eel. The 2015 and 2016 Nova Scotia eel fisheries were generally widely distributed with catches reported from 38 named river drainages.

Table 1. Summary of area (km² and expressed as a proportion of total available habitat—93,718 km²) of river drainages under hydroelectric development, fished for eels, fished for elvers, and where eels have been detected with the swim bladder parasite. Values are shown at the time of construction of the Mactaquac Dam (1969), the years 1970 – 2014, and for the years 2015, 2016, and 2017. Dashes (-) indicate data that is not available.

Time		Drainages	Area of Influence	
Period	**Activity**	**(n)**	**km²**	**Proportion**
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

Eels were fished within watersheds totaling 5,253 km² (5.6% AH), 4,841 km² (5.25% AH) of the drainage area also under hydroelectric development, and 92% (2015) and 86% (2016) of the estimated 38,037 km² (40.6% AH) of habitat known to contain the swim bladder parasite *A. crassus*. Eel and elver fisheries overlapped in watersheds totaling 7,864 km² (8.4% AH) and 5,238 km² (5.6% AH) during 2015 and 2016, respectively.

Concurrent eel and elver fisheries on rivers with installed hydroelectricity generating facilities occurred on two rivers representing approximately 4% (3797 km²) of AH in 2015 and on a single river representing approximately 2% (1936 km²) in 2016.

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 km² or approximately 35% of the 93,718 km² of drainage area available to recruiting elvers. The number of rivers where authorized elver fishing activities can take place increased from 65 in 1996 to 111 by 2004, and has been frozen at that number since 2004. The increase in rivers available for fishing 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 km² (26% AH) of the drainage area lying within DFO 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 DFO Maritimes Region AH.

Elver fisheries occurred in 92 (28.5% AH), 86 (27.4% AH), and 83 (27.5% AH) rivers during 2015, 2016, and 2017 respectively. The fishery footprint of directed elver fishing is modest at the regional level.

Elvers were fished within 10,388 km^2 (approximately 11% AH) of the drainage area under hydroelectric development in 2015 and 2016.

Elver fishing occurred in ≤12.5% of the estimated 38,037 km^2 (40.6% AH) of habitat known to contain *A. crassus*.

Spatial Overlap of Eel and Elver Fisheries

TOR 3. What has been the annual extent of spatial overlap of the commercial large eel and elver fisheries, since 2015?

The management strategy of limiting elver fisheries to rivers that have not been fished for large eels within any of the three prior years has limited the extent of overlap between the two fishery sectors to <10% of the habitat available to eels (Table 2). 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.

Fisheries independent data sources

Electrofishing

Freshwater fish communities are monitored by DFO in numerous NS and NB rivers using either annual or periodic electrofishing surveys. 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 freshwater. An extensive analysis of the annual and periodic surveys conducted in NS rivers (summarized in DFO 2017) affirmed the patterns of decline from series highs, perhaps by as much as 89% over 10 years. 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 has been tentatively planned for 2019.

Table 2. Summary of area (km² and expressed as a proportion of total available habitat – 93,718 km²) of river drainages under hydroelectric development, fished for eels, fished for elvers, and where eels have been detected with the swim bladder parasite for the years 2015 and 2016. The extent of overlap between two activities is shown. Dashes (-) indicate redundancy.

				Extent of Overlap With		
Year	**Units**	**Activity**	**Area (km²)**	**Eel**	**Elver**	**Parasite**
2015	**km²**	**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	-	-	-
	Proportion	**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	**km²**	**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	-	-	-
	Proportion	**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	-	-	-

Elver Abundance Indices

Currently, one fishery-independent elver abundance index is available, from the East River-Chester, although elver run size was also estimated on the East River-Sheet Harbour from 1996 – 1999. Mann-Kendall analysis of the observed estimates of the annual elver run size for the years 1996 – 2002 and 2008 – 2018 (Table 3) exhibited a statistically significant (n = 18, p = 0.03) increase with time. Predicted annual run size estimates to East River-Chester for the years 1990 – 1995, based upon the strong (r^2 = 0.97, p = 0.015) correlation with the 1996 – 1999 runs to East River-Sheet Harbour, varied between 93 kg (1995) and 313 kg (1991). Annual run size estimates for the years 2002 to 2007, based upon modelling the catch and effort of the commercial fishery, were less than 300 kg with the exception of 2006 (535 kg) (Table 3).

The observed series low occurred in 1999 (83 kg, approximately 530 thousand elvers) and the high occurred in 2018 (896 kg, approximately 3.8 million elvers). Elver run size exhibited high inter-annual variability with runs during adjacent years, differing by 50% or more in some years (Table 3, Figure 5). On average, elver runs to the East River-Chester have increased by between 50 – 70 thousand elvers per year, about 15 kg, since 1996 and by about 12 kg per year since 1990.

Table 3. Observed annual total elver run-size estimates (n) for East River(ER)-Sheet Harbour (years 1990 – 1999) and East River-Chester (n and kg wet weight, years 1990 – 2002 and 2008 – 2018). Predicted run size (kg) to the East River-Chester for the years 1990-1999 is based upon linear regression with the ER-Sheet Harbour estimates and for the years 1996 – 2018 is based upon a model that related elver run size to the total annual catch/effort for the elver licence whose fishing areas include East River-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

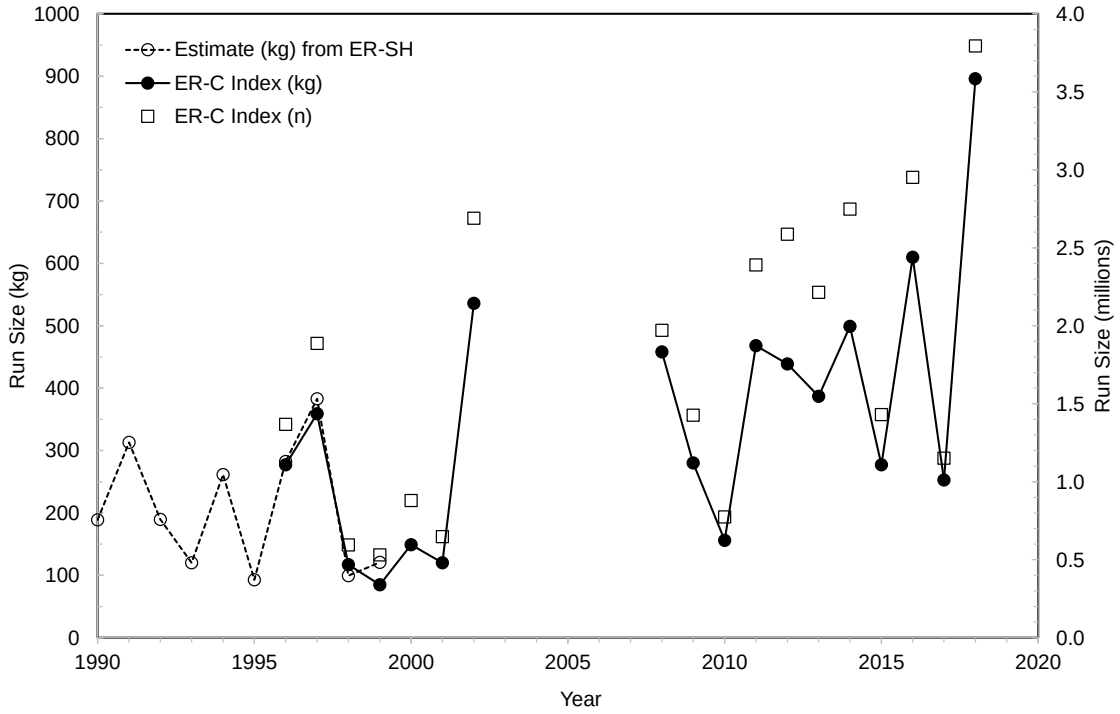

Figure 5. Elver run size (kg (closed circles) and millions of elvers (open squares)) to the East River-Chester (ER-C) versus year of sampling. Open circles show the predicted values from regression of the East River-Chester run size (kg) with East River-Sheet Harbour (ER-SH) run size (n).

RECOMMENDED MORTALITY REFERENCE POINTS FOR EELS

In 2009, DFO adopted the *Fishery Decision-Making Framework Incorporating the Precautionary Approach*, which explains how the Precautionary Approach will be put into practice in Canadian fisheries, including through the development of science-based reference points (DFO 2009). At the Framework review (DFO 2017), Spawner per Recruit (SPR) analysis (ICES 2001, Chaput and Cairns 2011) was recommended to define mortality reference points for all directed fisheries and hydroelectric facilities. The mortality rate that results in a 70% loss of spawning biomass relative to the population without losses from human activities (SPR30) was recommended as the limit removal reference (i.e., the maximum acceptable human-induced mortality rate). The mortality rate that results in a 50% loss of spawning biomass would be the target value (SPR50). The 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 human-induced mortality relative to a scenario where human-induced mortality is zero (Mace and Sissenwine 1993). The models require information on life history (growth rate, mortality rate, fisheries selectivity function) but do not require estimates of recruitment, and they do not assume a link between spawner abundance and recruitment. As presented, the models assume there is no density dependence.

The assessment of current mortality relative to reference points is limited to the elver fishery because of data limitations concerning eel harvests, eel biomass, and adult eel survival following downstream transit through hydroelectric facilities.

TOR 2. Based on a spawner-per-recruit 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

There are presently no estimates of yellow or silver eel production from the majority of rivers fished, which would be required for an assessment of fishing mortality rates relative to defined reference points. In the absence of these biomass indicators, assessment of fishery mortality rates are based on trends in landings over time, consistent with the inference made in the past that reduced harvests are synonymous with reduced exploitation rates (DFO 2010).

The SPR analyses applied to the assumed average life-history traits of DFO Maritimes Region eel populations give fishing mortality (F) reference points corresponding to SPR30 and SPR50 of 0.166 and 0.09, respectively, considering mortality from large eel fishing only.

It is not possible at this time to assess whether current fishing activities within individual river drainages are within acceptable limits given that only two years of robust catch and effort data are available. It can nonetheless be noted that eel fishing occurs in less than half of the watershed area available to eels at the regional level (Table 1). 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 facilities within 6% of the available habitat that was shared with eel fisheries (Table 2) and from an additional 11% of the available habitat that was shared with elver fishing (Table 2) could temper the view that eel fisheries have a moderate impact on regional adult eel production. Where eel and elver fisheries co-occur, increases beyond the target removal reference in either fishery would require a compensatory reduction in fishing mortality arising from the other, to be consistent with the management objectives (Figure 6).

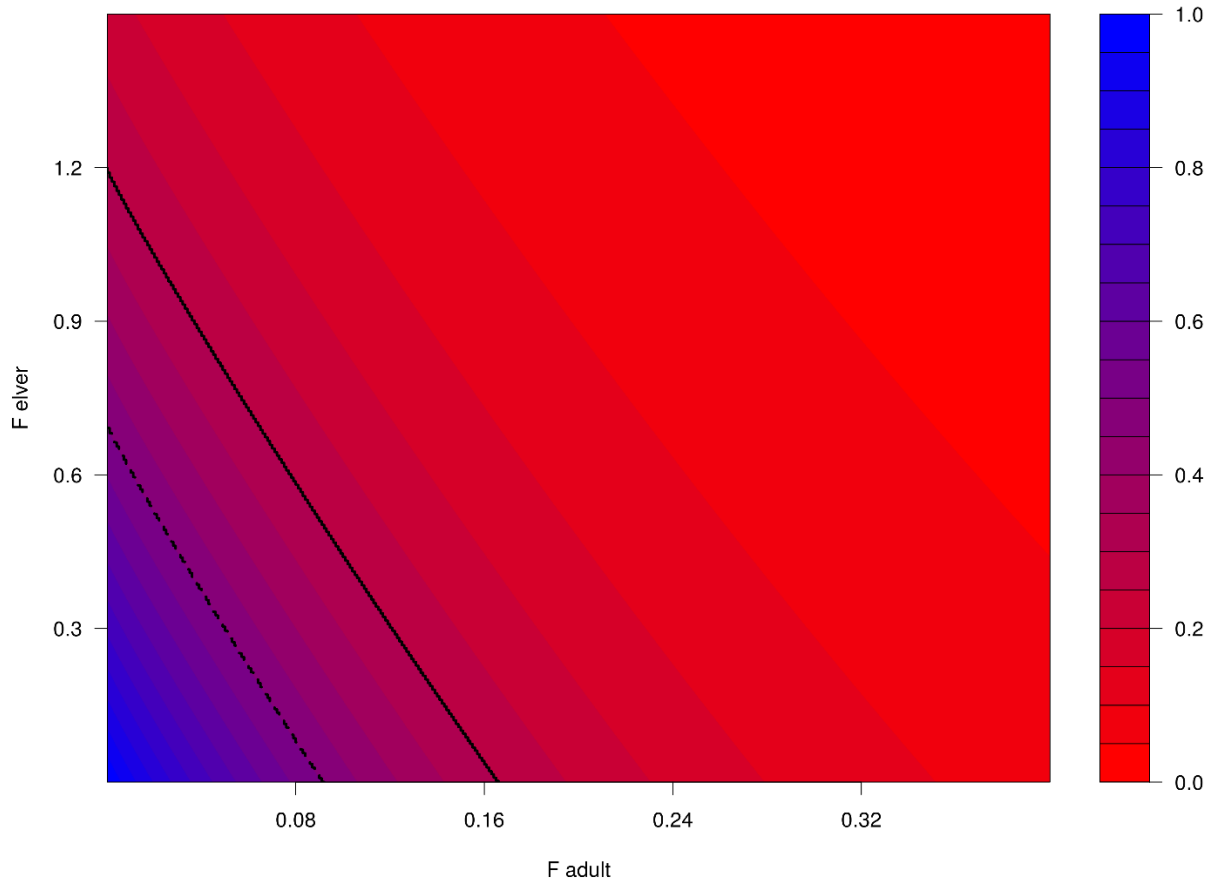

Figure 6. Spawner per recruit contours corresponding to combined exploitation in overlapping elver and adult eel fisheries for different levels of fishing mortality in each. The exploitation rates corresponding to SPR30 and SPR50 are represented respectively by a solid line and dashed line.

Hydroelectric Facilities

There is limited information available concerning the existence and effectiveness of upstream and downstream bypass facilities for American Eel in the DFO Maritimes Region. 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 two decades or more, are not well understood although it has been demonstrated that yellow eels in the Maritimes Region can migrate extensively between freshwater and tidal habitat (Jessop et al. 2002), indicating 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 adult eels.

Mortality reference points corresponding to SPR30 and SPR50 for eels during a single downstream pass through a hydroelectric generating facility were F = 1.204 and F = 0.693, respectively. Estimation of the mortality due to hydroelectric facilities on eel productivity cannot be assessed against these reference points at present, but they could be considered once estimates of turbine mortality are acquired.

Recommended Mortality Reference Points for Elver Fisheries

TOR 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 SPR analysis for the elver fishery is based on the derived natural mortality rate value for elver recruits, assuming no other human-induced mortality occurs on elvers escaping the fishery. The fishing mortality rates corresponding to SPR30 and SPR50 are 1.2 and 0.69, respectively, equal to exploitation rates of 0.69 and 0.49.

Direct evaluation of elver escapement past the localized East River-Chester elver fishery (years 1996-2002, 2008-2018) estimated that annual removals by elver fishing represented between 5% and 65% of the total elver run to the river. These removal rates are below the limit exploitation rate of 0.69 in all years but were above the target exploitation rate of 0.49) in 5 out of 17 years (Figure 7).

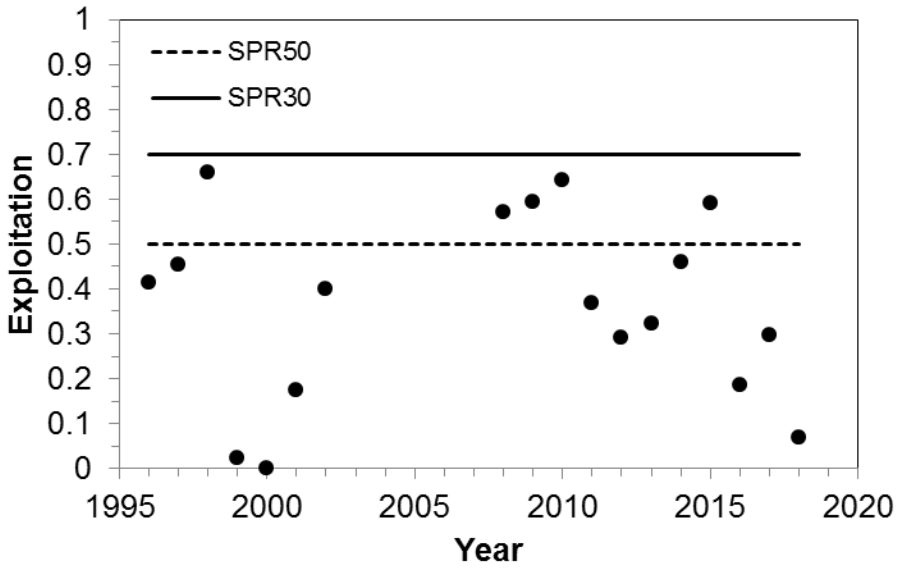

Figure 7. Observed exploitation rates for the East River-Chester elver fishery relative to exploitation rates corresponding to SPR30 (solid line) and SPR50 (dashed line). No fishing took place in 2000 and the elver index was not operated for 2003 – 2007.

For the 18 years of direct assessment in the East River-Chester, and based on a watershed area of 137 km², the median size of the elver run is estimated to be 2.33 kg km^{-2}. The harvest that could be realized at SPR50 is 1.14 kg km^{-2} and the harvest at SPR30 is 1.61 kg km^{-2}.

The potential harvest of elvers from individual rivers, scaled to the watershed area of the river and using a harvest rate equivalent to what could be extracted at SPR50 (exploitation rate = 0.49) and SPR30 (exploitation rate = 0.69), at an elver abundance equal to the median value from East River-Chester (2.33 kg km^{-2}), is shown in Figure 8.

The currently established individual river quota of 400 kg per river has not been achieved on rivers smaller than 250 km^2 and has only infrequently been approached on the larger river drainages (Figure 8). 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 limiting the ability to achieve the river quota on larger rivers.

There is a higher risk of fishing above F at SPR30 and SPR50 with a fixed river quota of 400 kg for drainages smaller than 250 – 300 km^2 (Figure 8).

The cumulative area of the drainages <250 km^2 that support elver fisheries is small (approximately 6%) relative to the total habitat available to eels, but it represents approximately 20% of the total area fished for elvers and about 70 to 73% of the drainages that have been actively fished annually beginning in 2015.

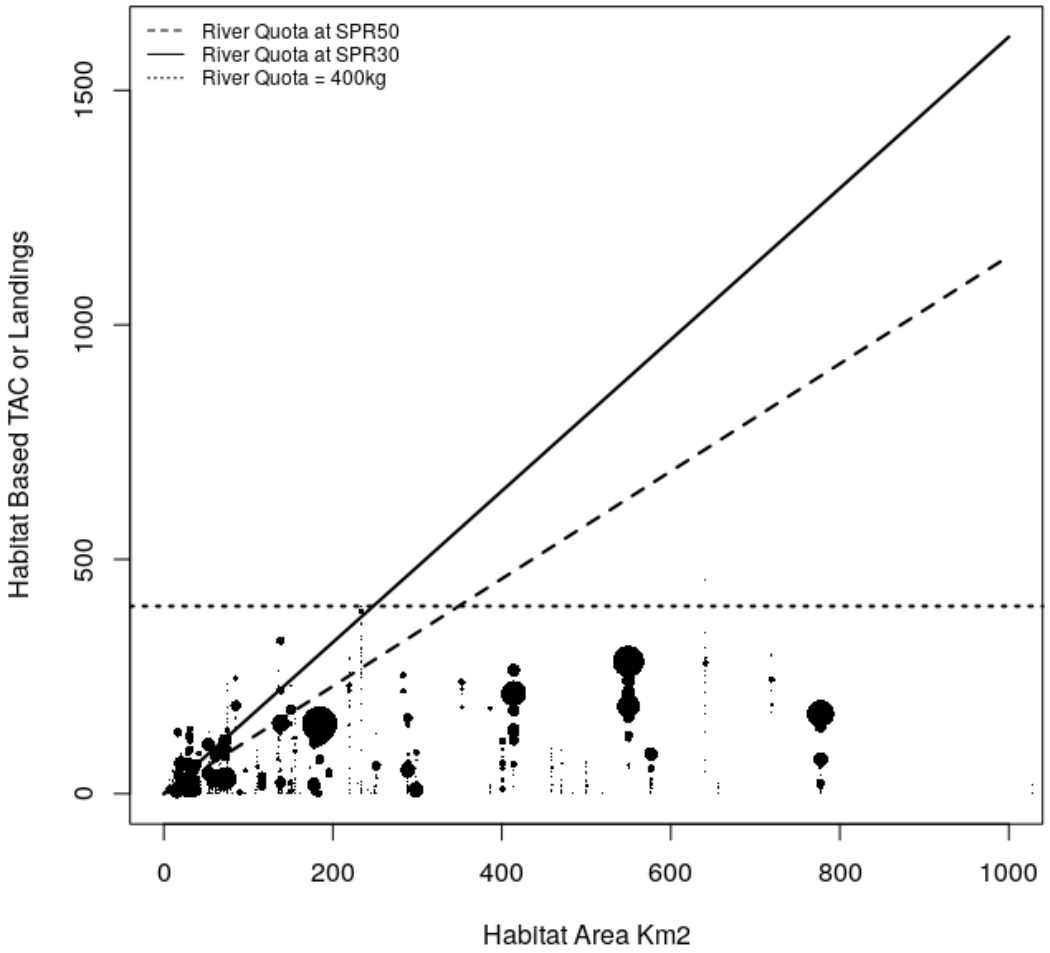

Figure 8. DFO Maritimes Region elver landings (over all rivers and years) versus the drainage area (km^2) associated with fishing locations. The horizontal dashed line depicts a constant river quota of 400 kg. The landings associated with fishing at SPR30 and SPR50 estimated from the observed run size and exploitation data from East River-Chester are shown as a function of the drainage area.

IMPLICATIONS FOR EXISTING MANAGEMENT MEASURES

TOR 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 commercial eel fishery in any detail, including in relation to the defined mortality reference points. The geographic footprint of the regional fishery, in terms of the watershed areas where eel fisheries occur, has been shown to be relatively modest. Participation rates are currently low relative to the fishing licences issued annually and to historical participation, as are the amounts of gear under active licences.

In combination, this may explain in part 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 is acquired to assess the status of the eel fishery with consideration of cumulative mortality arising from interaction with the elver fishery and hydroelectric utilities.

Under the assumption that elver recruitment across all fished watersheds and years has been at a level equal to the median observed values for East River-Chester, the existing river-specific elver fishery quotas have exceeded the target fishing rate at SPR50 and, in some cases, the maximum acceptable fishing rate defined by SPR30. It may be possible to set river-specific quotas that will vary with the watershed area using an estimate of elver abundance from the single monitored site, East River-Chester, as a guide (see Figure 8). These harvest levels, based on a median pre-fishery abundance of 2.33 kg of elvers per km² of watershed area and corresponding fishing mortality rate values at SPR30 and SPR50, are presently estimated to be 1.61 kg/km^2 and 1.14 kg/km^2, respectively. Historical landings in a river and other sources of human-induced mortality may also be considerations when setting river-specific quotas. The harvest levels at SPR30 are intended to be maximum values, whereas harvest levels at SPR50 are target harvest levels that are more in line with setting multi-annual quotas.

ASSESSMENT SCHEDULE AND CONTENT FOR UPDATES

TOR 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 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 reasonably occur every five years.

The observed increase in the elver recruitment at East River-Chester in recent years, albeit with significant interannual variability (Figure 5), indicates that the potential recruitment of elvers in the DFO Maritimes Region is not static and similar variations in large eel abundance would be expected. The recommended approach to establishing reference points to support precautionary management strategies under scenarios of changing productivity is to use as long as a time series of status indicators for the stock as possible and to establish the reference points on the basis of the long-term mean of the series (DFO 2009). The running median abundance for the East River-Chester elver recruitment index is recommended as the principle indicator of status. To account for the annual variation observed, a decline in the elver recruitment index based on the running mean over three years would be compared to the long-term median value of the 1996 to 2018 time series (2.33 kg/km^2). A re-assessment earlier than the proposed five-year assessment schedule may be warranted if the 3-year running mean of the elver recruitment index for East River-Chester falls below 2.33 kg/km^2. In 2018, the 3-year (2016 to 2018) mean value of the index was 4.28 kg/km², just under twice the median value (Figure 9).

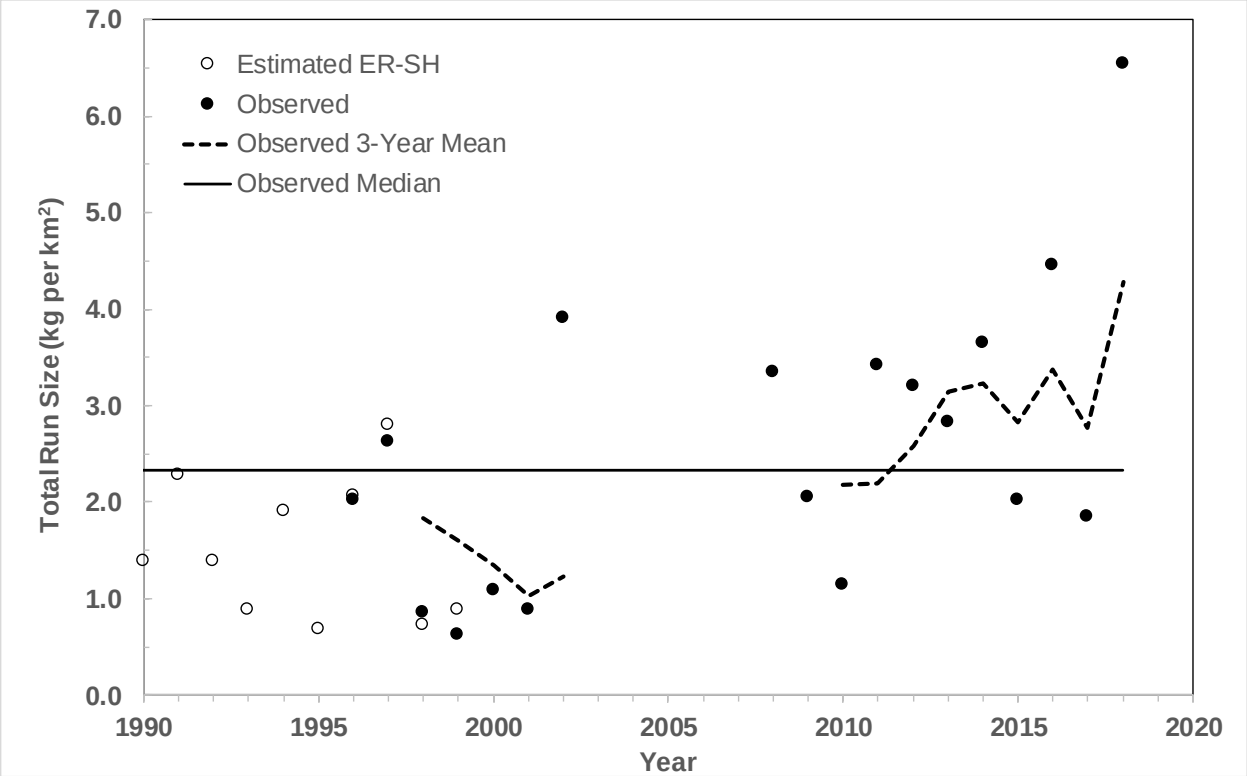

Figure 9. Observed (solid circles) and predicted (open circles) East River-Chester elver recruitment estimates expressed as kg per km² of watershed area for the years 1990 to 2018. The predicted values are based upon regression of the East River-Chester and East River-Sheet Harbour indices for the years 1996 – 1999. Shown are the long-term median (solid line) and the three-year running mean (dashed line) of the observed values.

There remains 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. A regional electrofishing survey is tentatively planned for 2019. 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 2021.

Updates between stock assessments would include the annual run size and escapement indices 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. Information concerning the large eel fishery could minimally include licencing and aggregate catch information for the most recent year of availability. Suggested inputs to interim updates are 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.

Sources of Uncertainty

Status of American Eel nationally was last assessed up to 2012 through a Recovery Potential Assessment in 2013 (DFO 2014). This assessment acknowledged that there have been declines in eel abundance indices, particularly in the St. Lawrence Basin. Current status of the panmictic stock of American Eel, in Canada and elsewhere, is not known.

Fisheries landings data derived from logbooks has improved but some deficiencies remain. The magnitude of the unreported catch from FSC, commercial communal, commercial and recreational fishing activities is not known. In particular, reporting is not required for recreational fishing and it is variable for FSC fishing.

Watershed area is a coarse measure of the scale of the potential fishery impact and does not take into consideration among-watershed variability in habitat type, eel recruitment, or eel production potential.

It is not known if elver availability overall is lower relative to the river drainages where elver fishing is currently practiced. This lends uncertainty to the use of the East River-Chester elver index as the sole index of recruitment, which was assumed to apply to elver recruitment broadly in the region. This assessment has not considered the effects of within- and among-year variability in environmental co-variates on elver catches and run size at East River-Chester, factors, which may affect the run sizes to the elver fishing locations in the region.

The potential loss in eel productivity that may result following infection with *A. crassus* is not known. An experimental evaluation (Warshafsky 2017) has indicated that the annual survival rate of infected yellow eels was 0.76 that of uninfected eels.

The relationship between recruitment of elvers and subsequent mature adult eel production one to several decades later is not known. The SPR analysis assumes that there is no density-dependence in the survival rates from elvers to adults, within the recruiting cohort of elvers, as well as between recruiting elvers and the resident standing stock consisting of a large number of older age classes.

CONCLUSIONS AND ADVICE

Stock status could not specifically be assessed because of data deficiencies. Elver recruitment in the Maritimes has increased since the last reporting of the index in 2013 (DFO 2014).

The current individual geographic footprints of the eel and elver fisheries are relatively moderate. In combination they occur within approximately 66% of available habitat, with less than 10% overlap.

The potential exists for the area subjected to directed fishing on American Eel to increase with time either through greater participation in the eel fishery or through an exchange of rivers presently fished for elvers for those that are larger in drainage area. Continuing to minimize the spatial overlap between eel and elver fisheries is an appropriate interim conservation measure until sufficient data is acquired to assess the extent of the cumulative mortality associated with fisheries at multiple life stages.

The assessment of current mortality relative to reference points is limited to the elver fishery because of data limitations concerning eel harvests, eel biomass, and silver eel survival following downstream transit through hydroelectricity generating facilities.

The fishing mortality reference values for large eels should be considered preliminary because a number of key inputs into the spawner per recruit analysis were either based upon average

traits or borrowed from populations outside the Region. Efforts should be made to improve spawner per recruit analysis for DFO Maritimes Region eels through collection of regionally representative biological and life-history data. Priority could be given to estimates of natural mortality at age, size at age, sex ratio, probability of maturing at age, and vulnerability to the human-induced mortality.

SPR analysis (ICES 2001, Chaput and Cairns 2011) was used to define mortality reference points for all directed fisheries and hydroelectric facilities. The mortality rate that results in a 70% loss of spawning biomass relative to the population without losses from human activities (SPR30) was recommended as the limit removal reference (ie, the maximum acceptable human-induced mortality rate). The mortality rate that results in a 50% loss of spawning biomass would be the target value (SPR50), summarized for the principal sources of mortality in Table 4:

Table 4. Reference points for principal sources of mortality of American Eels in the Maritimes Region. Dashes (-) indicate values that have not been determined.

Mortality Source		Target (SPR50)	Limit (SPR30)
Eels	F	0.09	0.166
	Exploitation	0.09	0.81
	Removal rate	-	-
Hydroelectric	F	0.693	1.204
	Exploitation	0.50	0.70
	Removal rate	-	-
Elver Fishery	F	0.69	1.2
	Exploitation	0.50	0.70
	Removal rate	1.14 kg/km^2	1.61 kg/km^2

Under the assumption that elver recruitment across all fished watersheds and years has been at a level equal to the median observed values for East River-Chester, the existing river-specific elver fishery quotas have in some cases exceeded either the target fishing rate at SPR50 or the maximum acceptable fishing rate defined by SPR30. The potential for over-fishing to occur appears to be highest on rivers ≤250 km^2 in drainage area. It may be possible to set river-specific quotas that will vary with the watershed area using an estimate of elver abundance from the single monitored site, East River-Chester, as a guide (see Figure 8). These harvest levels, based on a median pre-fishery abundance of 2.33 kg of elvers per km^2 of watershed area and corresponding fishing mortality rate values at SPR30 and SPR50, are presently estimated to be 1.61 kg/km^2 and 1.14 kg/km^2, respectively.

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