Fisheries and Oceans Canada
Ecosystems and Oceans Science

Pêches et Océans Canada
Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2021/032

National Capital Region

Stock-wide assessment framework for American eel: review of trends and approaches to assessment

M. Cornic[1], X. Zhu[1], and D.K. Cairns[2,3]

[1]Fisheries and Oceans Canada
Freshwater institute
501 University Crescent,
Winnipeg, Manitoba, R3T 2N6

[2]Fisheries and Oceans Canada
P.O. 1236
Charlottetown, Prince Edward Island, C1A 7M8

[3]Corresponding author: david.cairns@dfo-mpo.gc.ca

December 2021

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.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044
ISBN 978- 0-660-38453-5 Cat. No. Fs70- 5/2021-032E-PDF

Correct citation for this publication:

Cornic, M., Zhu, X., Cairns, D.K. 2021. Stock-wide assessment framework for American eel: review of trends and approaches to assessment. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/032. x + 77 p.

Aussi disponible en français :

Cornic, M., Zhu, X., Cairns, D.K. 2021. Cadre d’évaluation de l’anguille d’Amérique à l’échelle du stock : examen des tendances et approches en matière d’évaluation. Secr. can. de consult. sci. du MPO. Doc. de rech. 2021/032. xi + 81 p.

TABLE OF CONTENTS

ABSTRACT x

1. INTRODUCTION 1

2. METHODS 1

2.1. DATA SOURCES 1

2.2. FISHERY-DEPENDENT DATA 2

2.2.1. Canada 2

2.2.2. United States 2

2.2.3. Caribbean-Central America 2

2.2.4. Limitations 2

2.3. FISHERY-INDEPENDENT DATA 3

2.4. STATISTICAL ANALYSIS 3

2.4.1. Break-point analysis 3

2.4.2. Generalized linear mixed models 3

2.4.3. Power analysis 4

2.4.4. Mann-Kendall test 5

2.4.5. Autoregressive integrated moving average (ARIMA) models 5

3. RESULTS 6

3.1. LANDINGS 6

3.1.1. Canada 6

3.1.2. Outside Canada 6

3.2. STANDARDIZATION OF INDICES OF RELATIVE ABUNDANCE 7

3.2.1. Fishery-dependent indices 7

3.2.2. Fishery-independent indices 8

3.3. POWER ANALYSIS 11

3.4. TEMPORAL TRENDS 11

3.4.1. Lawrence Basin (SLB) 11

3.4.2. Scotia-Fundy (SF) 12

3.4.3. Southern Gulf of St. Lawrence (SG) 12

3.4.4. Northern Gulf of St. Lawrence (NG) 12

3.4.5. Temporal trends summary 12

3.5. AUTOREGRESSIVE INTEGRATED MOVING AVERAGE (ARIMA) AND FORECAST OF TRENDS IN ABUNDANCE 12

3.5.1. St. Lawrence Basin (SLB) 12

3.5.2. Scotia-Fundy (SF) 13

3.5.3. Southern Gulf of St. Lawrence (SG) 13

3.5.4. Northern Gulf of St. Lawrence 13

3.5.5. ARIMA models summary 13

4. DISCUSSION 14

4.1. LANDINGS ... 14
4.2. FISHERY-DEPENDENT ABUNDANCE INDICES ... 15
4.3. FISHERY-INDEPENDENT ABUNDANCE INDICES ... 15
4.4. STOCK STATUS DETERMINATION ... 16
5. CONCLUSIONS ... 16
6. RESEARCH RECOMMENDATIONS ... 17
ACKNOWLEDGEMENTS ... 17
REFERENCES CITED ... 17
TABLES ... 21
FIGURES ... 50

LIST OF TABLES

Table 1. Datasets reviewed and included in the stock assessment report to develop abundance indices for American eel in Prince Edward Island (PEI), Nova Scotia (NS), Quebec (QC), Newfoundland (NL), and Ontario (ON). 21

Table 2. Fishery-dependent and -independent surveys used to develop abundance indices for American eel in the St. Lawrence Basin (SLB), Scotia-Fundy (SF), Southern Gulf of St. Lawrence (SG), and Northern Gulf of St. Lawrence and Newfoundland (NG-NL). 22

Table 3. Variable types used to standardize abundance indices. 23

Table 4. Nominal abundance indices for American eel in the St. Lawrence estuary (kg per m). 23

Table 5. Model selection for fishery-dependent abundance indices in Nova Scotia (NS) and Prince Edward Island (PEI) using negative binomial (NB) GLM. Delta corrected Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error (rmse), statistical significance of the variables tested *p < 0.05, **p=0.01, ***p < 0.01. 24

Table 6. Abundance indices calculated using a negative binomial model (NB) and nominal abundance indices for winter spear fishery (kg of legal sized eels per spear-hour) (Gulf Nova Scotia). SE represents the standard error of the mean and blank cells indicate missing data. ..25

Table 7. Abundance indices calculated using a negative binomial model (NB) and nominal abundance indices for the fyke net fishery (kg of legal sized eels per net per day) (Gulf Nova Scotia). SE represents the standard error of the mean. 26

Table 8. Abundance indices calculated using a negative binomial model (NB) and nominal abundance indices for the fyke net fishery (kg of legal sized eels per net per day) (Prince Edward Island). SE represents the standard error of the mean. 27

Table 9. Model selection for the standardized abundance indices for St. Lawrence Basin (Ontario) for zero-inflated (ZINB) and negative binomial (NB) GLMMs. Delta corrected Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error (rmse), statistical significance of the variables tested *p < 0.05, **p=0.001, ***p < 0.001. 28

Table 10. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for trawling surveys (eels trawl^{-1}) in the Bay of Quinte (St. Lawrence Basin). SE represents the standard error of the mean and blank cells indicate missing data. Note that the increase in the index starting in 2012 is probably due to stocked eels. 30

Table 11. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices (eels per day) for fishway surveys in the Moses-Saunders Dam (St. Lawrence Basin). SE represents the standard error of the mean and blank cells indicate missing data. 31

Table 12. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices (eels per day) for fishway surveys in the Beauharnois Dam (St. Lawrence Basin). SE represents the standard error of the mean. 32

Table 13. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices (eels per day) for fishway surveys in the Chambly Dam (St. Lawrence Basin). SE represents the standard error of the mean. 32

Table 14. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices (eels per tidal cycle) (May to November) at Saint Nicolas (St.

Lawrence Basin). SE represents the standard error of the mean and blank cells indicate missing data. 33

Table 15. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices (eels per tidal cycle) for silver eels (October to November) at Saint Nicolas (St. Lawrence Basin). SE represents the standard error of the mean and blank cells indicate missing data. 34

Table 16. Model selection for the standardized abundance indices for Scotia-Fundy using zero-inflated (ZINB) and negative binomial (NB) GLMMs. Delta corrected Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error (rmse), r^2 marginal (r^2 marg), r^2 conditional (r^2 cond), variance statistical significance of the variables tested *p < 0.05, **p=0.01, ***p < 0.01....35

Table 17. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels $100m^{-2}$) in the Nashwaak River (Scotia-Fundy). SE represents the standard error of the mean. 37

Table 18. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels $100m^{-2}$) in the LaHave River (Scotia-Fundy). SE represents the standard error of the mean. 38

Table 19. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels $100m^{-2}$) in the St. Marys River (Scotia-Fundy). SE represents the standard error of the mean. 39

Table 20. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels $100m^{-2}$) in Scotia-Fundy rivers (Nashwaak, LaHave, and St Marys rivers). SE represents the standard error of the mean. 40

Table 21. Model selection for the standardized abundance indices for elvers in Scotia-Fundy using negative binomial (NB) GLMs. Delta corrected Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error (rmse), variance statistical significance of the variables tested *p < 0.05, **p=0.01, ***p < 0.01. 40

Table 22. Abundance indices calculated using a negative binomial model (NB) and nominal abundance indices for elver trap surveys (per kg) in East River Chester (Scotia-Fundy). SE represents the standard error of the mean. 41

Table 23. Model selection for the standardized abundance indices for the Southern Gulf of St. Lawrence for zero-inflated (ZINB) and negative binomial (NB) GLMMs. Delta corrected Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error (rmse), r^2 marginal (r^2 marg), r^2 conditional (r^2 cond), variance statistical significance of the variables tested *p < 0.05, **p=0.01, ***p < 0.01. 42

Table 24. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels $100m^{-2}$) in the Restigouche River (Southern Gulf). SE represents the standard error of the mean and blank cells indicate missing data. 43

Table 25. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels $100m^{-2}$) in the Miramichi River (Southern Gulf). SE represents the standard error of the mean. 44

Table 26. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels $100m^{-2}$) in New Brunswick rivers

(Restigouche and Miramichi rivers, Southern Gulf of St. Lawrence). SE represents the standard error of the mean. 45

Table 27. Model selection for the standardized abundance indices for the northern Gulf of St. Lawrence for zero-inflated (ZINB) and negative binomial (NB) GLMMs. Delta second-order Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error (rmse), statistical significance of the variables tested *p < 0.05, **p=0.01, ***p < 0.01....46

Table 28. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for trap surveys (per day) in the Sud-Ouest River (St. Lawrence Basin). SE represents the standard error of the mean. 47

Table 29. Results of power analysis for American eel abundance indices. For each survey linear and exponential trends were tested over a ten-year period. 47

Table 30. Mann-Kendal test (MK) and modified Mann-Kendal test (MK corrected) results for American eel abundance indices. NS represents a non-significant trend. 48

Table 31. Results for ARIMA model for fishery-independent data. Number of years (n), Standard error (SE), Variance (σ^2), Akaike information criterion (AIC), root mean square error (RMSE), Mean Error (ME), Mean Absolute error (MAE), Mean Percent error (MPE), Mean Absolute Percentage Error (MAPE), Mean Standard error (MSE), Autocorrelation Function (ACF). 49

Table 31 (continued). 49

LIST OF FIGURES

Figure 1. American eel Recovery Potential Assessment (RPA) Zones (from Cairns et al. 2014). 50

Figure 2. Fish surveys including American eel in Canada: a) fishery-dependent surveys and b) fishery-independent surveys. 51

Figure 3. Reported American eel landings in Recovery Potential Assessment (RPA) zones of Canada. Grey represents overall Canadian landings and black each RPA zone. Red lines indicate periods of change in landings as detected by the breakpoint analysis. 52

Figure 4. Reported American eel landings in coastal (upper panel) and freshwater (lower panel) habitat in Nova Scotia (NS) and New Brunswick (NB) in Scotia-Fundy (SF) and the southern Gulf of St. Lawrence (SG) management zones, and northern Gulf of St. Lawrence and Newfoundland (NG-NL). Quebec landings include silver eels caught in brackish and salt waters of the St. Lawrence Estuary, but these are included in the freshwater panel because they were reared in freshwater. Grey indicates the overall landings in Canada. 53

Figure 5. Reported American eel elver landings (top panel) and elver price per kg in Canada (lower panel). 54

Figure 6. Reported American eel landings in the US (upper panel) and overall landings (lower panel). 55

Figure 7. Nominal index (grey circles) of American eel for lower St. Lawrence trap net fisheries (kg per m). 55

Figure 8. Goodness of fit plots of the final model retained to standardize American eel CPUE in a) fyke net and b) spear fisheries in Nova Scotia (Southern Gulf of St. Lawrence). 56

Figure 9. American eel abundance indices for winter spearing (kg of legal sized eels per spear-hour) and fyke net (kg of legal sized eels per net per day) fisheries in Nova Scotia (Southern Gulf of St. Lawrence). The nominal index is denoted by grey circles while abundance indices and confidence intervals are indicated in green. 57

Figure 10. Goodness of fit plots of the final model retained to standardize American eel CPUE in fyke net fisheries in Prince Edward Island, Southern Gulf of St. Lawrence. 57

Figure 11. Abundance index of American eel for fyke net fisheries (kg of legal sized eels per net per day) in Prince Edward Island, Southern Gulf of St. Lawrence. The nominal index is denoted by grey circles while the abundance index and the confidence interval are indicated in green. . 58

Figure 12. Goodness of fit plots of the final model retained to standardize American eel abundance in the St. Lawrence Basin (Ontario): a) the Saunders ladder of the Moses-Saunders Dam and b) Bay of Quinte. 59

Figure 13. Abundance index for American eel in the St. Lawrence Basin (Ontario) from the Saunders ladder of the Moses-Saunders Dam (eels per day) and Bay of Quinte (eels $100m^{-2}$). Nominal index is denoted by grey circles while abundance index and confidence interval are indicated in green. 60

Figure 14. Length frequency of American eels at the Moses-Saunders Dam from 2006 to 2018. 60

Figure 15. Goodness of fit plots of the final model retained to standardize American eel abundance in the St. Lawrence Basin: a) Beauharnois Dam, b) Chambly Dam, c) Saint Nicolas trap (May to October), and d) Saint Nicolas trap (September-October). 61

Figure 16. Abundance index for American eel in the St. Lawrence Basin in Quebec from the Beauharnois Dam (eels per day), the Chambly Dam (eels per day), and the Saint Nicolas trap (eels per tidal cycle). The nominal index is denoted by grey circles while the abundance index and confidence interval are indicated in green. For Saint Nicolas, green indicates the index corresponding to silver eel catches (September-October) and orange indicates the index corresponding to a mix of yellow and silver eel catches (May-October). 62

Figure 17. Length frequency of American eel at Beauharnois Dam from 2002 to 2018. 63

Figure 18. Length frequency of American eel at the west pass of Chambly Dam from 2006 to 2018. 63

Figure 19. Goodness of fit plots of the final model retained to standardize American eel abundance in Scotia-Fundy: a) Nashwaak River, b) LaHave River, c) St. Marys River, and d) all rivers combined. 64

Figure 20. Abundance indices for American eel (eels $100m^{-2}$ in the first electrofishing pass) in Scotia-Fundy from electrofishing surveys in the Nashwaak River, the LaHave River, the St. Marys River, and all rivers combined. The nominal index is denoted by grey circles while the abundance index and confidence interval are indicated in green. 65

Figure 21. Length frequency of American eel in the Nashwaak River from 2013 to 2018. Note that the length was not recorded with the same method in 2013 (n=50, average 24.7cm) and 2017 (n=85, average 24.4 cm). 66

Figure 22. Length-weight relationship of American eel in the Nashwaak River (Scotia-Fundy) from 2013 to 2018. 66

Figure 23. Goodness of fit plots of the final model retained to standardize American eel elver abundance in Nova Scotia (Scotia-Fundy). 67

Figure 24. Abundance index for elvers (kg per day) in Nova Scotia (Scotia-Fundy) from trap surveys. The nominal index is denoted by grey circles while the abundance index and confidence interval are indicated in green. 67

Figure 25. Goodness of fit plots of the final model retained to standardize American eel abundance in the Southern Gulf of St. Lawrence: a) Restigouche River, b) Miramichi River, and c) all rivers combined. 68

Figure 26. Abundance index for American eel (eels $100m^{-2}$) in the Southern Gulf of St. Lawrence from electrofishing surveys. The bottom panel represents the abundance index for the Restigouche River and Miramichi River combined. The nominal index is denoted by grey circles while the abundance index and confidence interval are indicated in green. 69

Figure 27. Goodness of fit plots of the final model retained to standardize American eel abundance in the Northern Gulf from Sud-Ouest River trapnet surveys. 70

Figure 28. Abundance index for American eel (eels per day) in the Northern Gulf. The nominal index is denoted by grey circles while the abundance index and confidence interval are indicated in green. 70

Figure 29. Length frequency of American eel in the Sud-Ouest River from 2004 to 2014....71

Figure 30. Length-age relationship of American eel in the Sud-Ouest River (Quebec), 2004 to 2013. 71

Figure 31. Spearman correlation matrix for fishery-independent abundance indices. The scale of the colors is denoted as follows: the more positive the correlation (closer to 1) the darker the shade of red; the more negative the correlation (closer to −1) the darker the shade of blue. 72

Figure 32. Residual diagnostics and ARIMA models of American eel abundance indices in the St. Lawrence Basin. Blue lines represent the projection of American eel abundance for the next ten years and blue shades their confidence intervals (80% in dark shade and 95% in light shade). 73

Figure 32 (continued). 74

Figure 33. Residual diagnostics and ARIMA models of American eel abundance indices in Scotia-Fundy. Blue lines represent the projection of American eel abundance for the next ten years and blue shades their confidence intervals (80% in dark shade and 95% in light shade). 75

Figure 34. Residual diagnostics and ARIMA models of American eel abundance indices in the Southern Gulf of St. Lawrence. Blue lines represent the projection of American eel abundance for the next ten years and blue shades their confidence intervals (80% in dark shade and 95% in light shade). 76

Figure 35. Residual diagnostics and ARIMA models of American eel abundance indices in the Northern Gulf of St. Lawrence. Blue lines represent the projection of American eel abundance for the next ten years and blue shades their confidence intervals (80% in dark shade and 95% in light shade). 77

ABSTRACT

American eel population status in Canada was last assessed in 2012 and 2014. The present report re-assessed American eel abundance indices and investigated temporal trends in relative abundance in five management regions. Assessment included fishery-dependent and -independent data; however, the lack of data in several regions and/or for different life stages limited our ability to fully evaluate American eel population trends in Canada.

Between 1874 and 2016, reported American eel landings in Canada varied between 200.6 and 1411.7 tons. From the 1880s to 1990 reported landings fluctuated without an overall trend, but showed relative stability in the 1970s and 1980s. Since about 1990 reported landings have steadily decreased.

Fishery-independent indices, updated since the last assessment, were developed using generalized linear mixed models including temporal, environmental, and effort variables to account for changes in catchability. Overall, 12 fishery-independent datasets were evaluated of which 9 reflected yellow eel abundance. Trend analysis indicated that American eel abundance was stable (6 surveys), declining (4 surveys) or increasing (2 surveys). The 25th percentile reference point when compared to the initial year indicated 8 downward trends; however, when the 25th percentile reference point in the terminal year was compared to those in 2012 an increase in abundance was observed for 5 surveys over the last 5 years.

Reference points for defining the stock status of American eel in Canada were not estimated as further data and analysis are needed. However, trends in relative abundance are similar to the last stock assessment in 2012 and recovery plan in 2014. Commercial landings and fisheries-independent surveys suggest that American eel abundance has been stable since 2000 but at low abundance and the downward trend in several surveys remains a concern for the recovery of the population in Canada. Therefore, the American eel population is similar to 2012 and its stock continues to be at risk. We recommend continued monitoring and data gathering in order to better evaluate American eel status in Canada.

1. INTRODUCTION

The American eel (*Anguilla rostrata*) is considered to be a panmictic species with a vast continental range extending from Greenland to northern South America. Historically no fisheries occurred in the southern part of this distribution but the species has been extensively fished in certain parts of the Atlantic drainages of North America (Casselman 2003). Reported landings have undergone successive peaks and valleys since the advent of statistics-keeping in Canada and the US in the 1870s and 1880s. After the 1980s, species-wide landings undertook a long decline which has heightened concerns about American eel conservation and fisheries sustainability (COSEWIC 2012, ASFMC 2017).

Recent stock reviews based on fishery-dependent and fishery-independent data considered the American eel stock to be depleted in East Coast US waters (ASFMC 2017) and threatened in Canada (COSEWIC 2012). American eel ecology is complex and incompletely understood, which limits our understanding of population dynamics, habitat and life stage requirements. In 2013, the Canadian Science Advisory Secretariat (CSAS) conducted a Recovery Potential Assessment (RPA) for the Canadian segment of the American eel stock, as part of the Canadian Species at Risk process (Cairns et al. 2014, Chaput et al. 2014a,b, DFO 2014, Pratt et al. 2014). e Reports generated by the RPA included information on landings, abundance indices and demographic parameters, habitats, and threats. While stock status was not determined, the review indicated declines in American eel population indicators over 32 years (two freshwater generations) but no consistent change over the most recent 16 years (one freshwater generation). The review also highlighted substantial regional variations in abundance trends.

Changes in fishing effort and habitat degradation (dams, pollution, introduction of alien species) may explain the regional variations observed in American eel abundance. Over the last several decades, long-term fishery-dependent and -independent datasets were developed in eastern Canada (Cairns 2020). Freshwater habitats have been considered as essential to eels and information available for stock assessments has been largely from fresh water. American eel growth and maturation schedules in northeastern North America are highly salinity-dependent, with eels reared in fresh water having about one half the growth rate and double the time to maturation compared to eels reared in brackish and salt water (Thibault et al. 2007; Cairns et al. 2009; Jessop 2010). Temperature may also influence American eel life history (i.e., maturity, growth, migration) (Jessop 2010). Because these and other factors may influence catchability, use of catch per unit effort series to indicate abundance trends requires standardization by environmental factors.

Long-term series of American eel commercial landings (1874-2016) and abundance indices (1952-2018) were compiled and reviewed during a CSAS meeting held in Ottawa in May 2019 (Cairns 2020). The objectives of this report are to use this information to investigate how dynamics in landings potentially impacted American eel populations and to develop abundance indices based on research surveys to detect changes in American eel abundance in Canada.

2. METHODS

2.1. DATA SOURCES

The American eel range in eastern Canada (excluding Labrador) was divided into four zones for the RPA (Cairns et al. 2014): the St. Lawrence Basin (SLB), Scotia-Fundy (SF) corresponding to the Atlantic and Bay of Fundy drainages of New Brunswick and Nova Scotia, the Southern Gulf of St. Lawrence (SG) including Prince Edward Island and the Gulf of St. Lawrence drainages of New Brunswick and Nova Scotia, and the Northern Gulf of St Lawrence and Newfoundland (NG-NL; Fig.1). Fishery-dependent datasets including catch data and in some cases fishing effort, and fishery-independent datasets from long-term monitoring programs were available for each zone. These datasets have been updated since the last American eel review in Canada (Cairns et al. 2014) and subject to expert review with an emphasis on evaluating series for error and bias (Cairns 2020). Based on their findings, datasets were classified depending on their quality and usefulness to reflect American eel abundance trends in Canada (Table 1). A full description of the fishery-dependent and -independent data collection is presented in Cairns (2020).

2.2. FISHERY-DEPENDENT DATA

2.2.1. Canada

Commercial fisheries in Canada target two main life stage categories: large eel > 35 cm (yellow and silver eels) and eels < 10 cm (glass eel and elvers). In Canada, eels under 10 cm are legally defined as elvers, and this term is used in this paper to encompass both glass eels and elvers. Large eel landings data are available from 1874 in most of Canada. Elver landings are available from 1989 to 2017. In addition to annual landings, large eel commercial logbook records were also available for trap net fisheries in the St. Lawrence estuary and fyke net and winter spear fisheries in Prince Edward Island and in the Nova Scotia portion of the southern Gulf of St. Lawrence (Fig. 2; Table 2). These logbooks reported daily fishing effort and catch.

Large eel fisheries have occurred in all provinces of eastern Canada. Landings in the Atlantic provinces were reported by the Department of Fisheries and Oceans while landings in Quebec and Ontario were reported by provincial agencies. Elver fisheries occur only in the Atlantic provinces and landings are reported by the Department of Fisheries and Oceans.

2.2.2. United States

Commercial landings of large American eels are reported in US Atlantic and Gulf of Mexico drainages. We report landings by three RPA zones: Atlantic Seaboard North, Atlantic Seaboard Central, and Atlantic Seaboard South (Fig. 1). Elver fisheries also occur in Maine and South Carolina. Landings are from US government reports (Cairns 2020).

2.2.3. Caribbean-Central America

The United Nations Food and Agricultural Organization (FAO) compiles worldwide fisheries landings, but American eel landings for the Caribbean Basin and Mexico are considered unreliable. Landings for this region are taken from information supplied to the American eel Range States Workshop in Santo Domingo, Dominican Republic, in April 2018 (Cairns 2020).

2.2.4. Limitations

Fishery landings are influenced by multiple factors, including price, availability of alternate employment or fisheries targets, effectiveness of available fishing gear, and fishing regulations. For fisheries catch per unit effort to be proportional to population abundance, catchability must be constant over time (Hilborn and Walters 1992; Harley et al. 2001; Walters 2003). For these reasons, reported fisheries landings may have little relation to fish abundance. Nevertheless, data on fisheries removals are essential in the determination of fisheries effects on eel abundance, age and size.

2.3. FISHERY-INDEPENDENT DATA

Cairns' (2020) review of fisheries-independent series identified several datasets that had quality problems or insufficient series length. Consequently, some datasets used during the previous assessments were not carried forward to the present analysis (Table 1).

Long-term monitoring surveys (>15 years) in the SLB, SF, and SG zones were used to develop abundance indices of American eel in Canada (Fig. 2). SLB surveys in Ontario consisted of bottom trawl surveys in the Bay of Quinte and eel ladder counts at the Moses-Saunders Dam while surveys in Quebec included eel ladder counts from the Chambly and Beauharnois Dams and experimental trapnets at Saint Nicolas. Electrofishing surveys (1st sweep) were performed in the Nashwaak, LaHave, and St. Marys Rivers in SF. Densities from electrofishing surveys were used as the abundance indicator in the Restigouche and Miramichi Rivers in SG (Table 2). In NG-NL, eel catches were recorded from traps in the Sud-Ouest River. American eels caught during these surveys were mostly yellow phase (Table 2); therefore, the analyses conducted in this study are representative of yellow eel abundance unless otherwise mentioned. In addition to these surveys, elver recruitment was monitored using traps in East River Chester in Nova Scotia (DFO 2017, DFO 2019). Full descriptions of data sources are provided by DFO (2019) and Cairns (2020).

2.4. STATISTICAL ANALYSIS

2.4.1. Break-point analysis

Commercial landings of American eels in Canada were analyzed to determine if structural changes occurred since 1874. Break-point analysis was performed to detect one or more structural breaks in commercial landings based on piecewise linear models using a dynamic programming approach (Bai and Perron 2003). This approach selects optimal breakpoints that result in a minimization of the residual sum of squares. An F-test to determine if at least one structural change occurred in the time series was performed, then, the adequate optimal number of breakpoints was selected based on the lowest Bayesian information criterion (BIC) (Zeileis et al. 2003). For each breakpoint, 95% confidence intervals were calculated. Breakpoint analyses were conducted using the ‘strucchange’ package in R (Zeileis et al 2015).

2.4.2. Generalized linear mixed models

A previous review of American eels in Canada (Cairns et al. 2014) used generalized linear models (GLM) to develop abundance indices. Environmental conditions were not included in the models. However, such conditions are major factors affecting American eel life history and in turn, their catchability. In the present assessment, generalized linear models (GLM) and generalized linear mixed models (GLMM) were developed to estimate the abundance indices of American eel in the various zones. The number of American eels was modeled by a set of temporal and environmental explanatory variables (Table 3) and an offset term for effort. When environmental covariates were not recorded during survey operations, temperature (°C), river flow (m/s^{-3}), and water level (m) were downloaded for each site (closest gauge) and sampling day (Expertise hydrique et barrages; Water Level and Flow; Historical Climate Data; St. Lawrence Global Observatory). Survey design and field data collection methods are described in Cairns (2020).

Before building the GLMMs, outliers were removed from the analysis and collinearity between independent variables was investigated using Spearman correlations (r<0.5) and the variance inflation factor (VIF<3). If two variables were collinear, two models were developed with each collinear variable and the variable included in the better model was retained for further analysis.

The best model selection was based on the lowest Akaike information criterion (AIC). Delta corrected AIC (ΔAICc), residual patterns and dispersion tests (Hartig 2019), R-squared (Lüdecke 2019), and the root square error (RMSE) were examined to check the performance of the models. The TMB package in R (Brook et al. 2017) was used to fit the generalized mixed models. All statistical analyses were implemented in R (R Core Team, 2019).

2.4.2.1. Fisheries-dependent models

Fisheries-dependent datasets were characterized by a skewed distribution of the data; however, fewer than 2% of data points were zero. Moreover, the number of fishers in the datasets varied among years resulting in small number of levels which can lead to imprecise estimates of random effect or lack of convergence. Therefore, the fisher variable was not included as a random effect but as a factor in the fishery-dependent models and GLMs with a negative binomial distribution were developed to standardize fisheries catches.

2.4.2.2. Fisheries-independent models

Because a large number of zeros was observed in fisheries-independent datasets accompanied by a skewed distribution, standard negative binomial and zero-inflated negative binomial GLMMs were developed. Zero-inflated models allow for large number of zeros in count models by calculating the presence-absence of American eel and then their positive catches to estimate "true" zero catch. Presence-absence was modeled on a binomial distribution with a logit link while the positive catch component was modeled with a negative binomial distribution and log link. Then, performance of the models was compared and the model fitting best the data was selected to standardize American eel catches. Note that the explanatory variables included in the initial models might differ among zones and surveys depending on the availability of the data, and variables used in each part of the zero-inflated GLMM were not necessarily the same. Because different sites were sampled during bottom trawl surveys and electrofishing surveys, a random effect representing spatial variations (site) was included to standardize catches in these surveys. For each dataset nominal indices were also calculated (number of fish per area or day).

2.4.3. Power analysis

To detect the probability of identifying trends in the standardized fisheries-independent abundance indices, power analysis (Gerrodette 1987) was developed using the R function power.trend (Nelson 2018). Changes in abundance were modeled following linear (equation 1) and exponential (equation 2) approaches to consider the changes at constant increments and rates, respectively.

Equations 1: $A_i=A_1[1+r(i-1)]$ and $r=R/(n-1)$

Equations 2: $A_i=A_1(1+r)^{i-1}$ and $r=(R+1)^{1/(n-1)}-1$

where A_i represents the abundance in a specific year (i), r is a constant increment of change as a fraction of the starting abundance index (A_1) and R is the overall fraction change in abundance.

The median CV or proportional standard error, was calculated as the median proportional standard error ($SE(A_i)/A_i$)) and power (R) corresponded to the probability of ±50% change over 10 years (r=0.056) for each survey for linear and exponential approaches. A reference point of a power of 0.80 for surveys was used to detect an increasing trend. Data were analyzed at the $\alpha=0.05$ significance level.

2.4.4. Mann-Kendall test

Twelve fishery-independent surveys that were developed into abundance indices were evaluated using the Mann-Kendall test to detect temporal trends in abundance indices from the different zones in Canada. This is a non-parametric test for monotonic trends in time-ordered data (Gilbert 1987). Because some data showed autocorrelation using ACF function, a modified Mann-Kendall test was also used (Hamed and Roa 1998; Patakamuri and O'Brien 2019) to prevent the detection of false trends and Sen's slope method was employed to quantify the degree of temporal trend.

2.4.5. Autoregressive integrated moving average (ARIMA) models

Understanding abundance trends and the ability to forecast American eel catches are valuable in the development of management strategies. Auto-regressive integrated moving average (ARIMA) models were used to fit and forecast American eel abundance indices. ARIMA models are flexible and assume that future conditions are similar to the past conditions that produced catch forecasts, and have been successfully implemented for commercial fish species (Fogarty and Miller 2004; Kim et al. 2015; ASMFC 2017).

In stock assessments, ARIMA models can be used to determine population status relative to an index-based reference point (Helser and Hayes 1995; ASMFC 2017). An index-based reference point is defined as a reference point corresponding to a value within the observed range of values for the relative abundance index. The probability of a fitted index value of a specific year (i.e. index start and/or final year of the survey) being less than the reference point is provided using a bootstrapping method. Chosen reference points were the 25th percentile of the fitted abundance index and correspond to 80% confidence intervals. The 25th percentile was selected because it provides a reasonable reference point for comparison for data with relatively high and low abundance over a range of years (Helser and Hayes 1995). The reference point was compared to the initial year of the survey and 2012 to investigate a potential change in abundance in the long-term time series and since stock status of American eel was last evaluated (COSEWIC 2012).

ARIMA models assume that time series are stationary with a stable variance throughout the time period. Because our data violated this assumption, American eel abundance indices were transformed and a constant was used to account for zeros (log(index+0.01)) prior to fitting the ARIMA model. Long-term data are more effective in time series analysis; therefore, surveys with more than 15 years observations were fitted using ARIMA models. Selection of the candidate model was based on sample estimates of the autocorrelation function (ACF) and partial autocorrelation function (PACF) in order to select the three major orders of the ARIMA (p, d, q) model, where p is the number of autoregressive terms, d is the number of non-seasonal differences needed for stationarity, and q is the number of lagged forecast errors in the prediction equation. Then, the accuracy of the model was evaluated using Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Root Mean Square Error (RMSE), Mean Absolute Scaled Error (MASE) and Mean Absolute Error (MAE), and residual diagnostics. Model fit and predictions were implemented using the fishmethod R package (Nelson 2018) and the forecast R package (Hyndman et al. 2019).

3. RESULTS

3.1. LANDINGS

3.1.1. Canada

Total landings of large American eels in Canada combine the catches of the St. Lawrence Basin (SLB), Scotia-Fundy (SF), Southern Gulf of St. Lawrence (SG), and Northern Gulf of St Lawrence and Newfoundland (NG-NL) from 1874 to 2016 (Figs. 3-4). American eel landings were highly variable ranging from 200.6 tons in 1941 to 1411.7 ton in 1888. To determine if major changes occurred in landings, a breakpoint analysis was performed. A significant structural change in landings was observed (F=66.1; p<0.01) and five periods were detected: 1874 to 1908 (mean 914.3 ± 47 tons), 1909 to 1938 (mean 729.9 ± 46 tons), 1939 to 1966 (mean 544.7 ± 29.5 tons), 1967 to 1993 (mean 998.5 ± 29tons), and 1994 to 2016 (mean 483.4 ± 32.3 tons) (Fig. 3). Landings reached a maximum during the fourth period (1967-1994) with a peak in 1971 (1223 tons) followed by a fairly stable period from 1970 to 1994. Then, American eel landings declined, falling to a minimum in 2015 (296 tons) which represented a decrease of 61% over 11 years. Overall, landings in the most recent period have been lower than historical landings.

Variations in landings were recorded at the regional level with SLB representing 55% of the overall landings followed by SG (30%), SF (10%), and NG-NL (5%) (Fig. 4). Overall SLB represented the largest part of American eel's landings; however, a sharp decrease was observed in the most recent period, with a decline of 94% between 1990 and 2015. Quebec landings dominated SLB landings (90%) indicating the importance of this province in the commercial fisheries of American eel in Canada. In contrast, landings in the Atlantic regions (SG, SF and NG-NL) were relatively stable over the last 20 years. In this period, a majority of the landings came from SG, particularly in New Brunswick (55%) where an increase of 42% was detected between the 1990s and the 2000s. The difference in landings trends among zones revealed a shift in American eel's landings since 2000. While SLB dominated American eel landings from 1874 to 2000 (62%), nearly half (48%) of the landings are now reported in SG, followed by SLB (23%), SF (18%) and NG-NL (12%).

Commercial elver fisheries also occurred in Nova Scotia and New Brunswick in Canada. These fisheries have grown since 1989 despite the implementation of a restriction of 9 commercial fisheries licences in 1998 (Fig. 5). Elver landings in the Atlantic region from 1989 to 2010 averaged 1.7 tons and increased to 6.8 tons in 2013 before stabilizing at a high level since 2014 (mean 5±0.4 tons). Simultaneously, elver market price in Canada increased, reaching a maximum of \$4680 kg^{-1} in 2015 (Fig. 5).

3.1.2. Outside Canada

US landings of large eels from 1920 to 2016 showed similar trends to Canadian landings with a peak in 1979 (1792.5 tons) followed by a sharp decrease until the present time (mean 602.51±46.3 tons) (Fig. 6). Landings were dominated by Atlantic coast fisheries (99.9%) with minor contributions from Gulf of Mexico drainages (<0.01%). Further to the south, minimal catches were reported in Caribbean Basin (Fig. 6). However, before 1970 US commercial landings most likely included several species and US landings might not reflect only American eel. While landings are reported in Cuba since 1974, large American eel fisheries are stable since 2001 ranging from 3 to 3.5 tons over the last 20 years.

Elver fisheries occur on the US east coast and Caribbean islands. In the US, commercial elver fisheries continuously increased since 1989, peaking in 2013 at 19.5 tons (Fig. 5).

Subsequently, and coincident with more restrictive management measures, reported landings declined to 6.2 tons in 2015 and 9.5 tons in 2016. In the Caribbean (Haiti, Republic Dominican, Jamaica), elver landings significantly rose since 2012 reaching a peak in 2014 (14.8 tons) (Fig. 5).

3.2. STANDARDIZATION OF INDICES OF RELATIVE ABUNDANCE

3.2.1. Fishery-dependent indices

3.2.1.1. Lower St. Lawrence traps (SLB)

Trap fisheries from the lower St. Lawrence estuary were investigated using different models and distributions. Overall, models showed a significant deviation of residuals indicating that the models did not fit the data well. Because the data in this region were considered as good quality based on nominal abundance by a panel of experts (Table 1), the abundance index presented in this report corresponds to nominal abundance (Fig. 7). The index shows that the lower St. Lawrence fisheries were relatively stable from 1996 to 2015 with a maximum reached in 2006 (6.85 kg per m) (Table 4).

3.2.1.2. Winter spear fisheries in Nova Scotia (SG)

The final model included year, month, fisher (AIC= 5571). All covariates were significant (Table 5). No obvious pattern in the plots of the residuals was observed (Fig. 8). The abundance index was similar to the nominal index (4.4±0.5 kg of legal sized eels per net per spear-hour and 4.5±0.5 kg of legal sized eels per net per spear-hour), indicating that the winter spear fisheries in Nova Scotia steadily increased from 1998 to 2018 (Table 6; Fig. 9).

3.2.1.3. Fyke net fisheries in Nova Scotia (SG)

The fyke fisheries final model retained year, month and fisher (AIC=3045; Table 5; Fig. 8). The covariates year and fisher were significant. However, only the year 2017 was significantly different than the other years. Nominal and abundance indices were similar (2.8±0.6 and 2.9±0.6 kg of legal sized eels per net per day) and both trends indicated that American eel catches were steady from 1998 to 2016 and reached a maximum in 2017 (Table 7; Fig. 9). Overall, fyke fisheries increased over the last 20 years.

3.2.1.4. Fyke net fisheries Prince Edward Island (SG)

Only temperature was included as an environmental variable in the full model to standardize American eel catches in PEI fyke net fisheries. The best model retained year, month and fisher (AIC=93130, Table 5). However, the residual plot showed a deviation in the residual distribution (Fig. 10) indicating that the model might not fit accurately the data. Different models with several distributions were tested but did not improve the model fitness. Overall, the abundance index and the nominal index indicated similar trends with a constant increase in American eel catches since 1997 (Table 8; Fig. 11).

3.2.1.5. Fishery-dependent abundance index summary

Detailed fishery-dependent data provided complementary spatial data on American eel abundance and permit the estimation of American eel abundance in several rivers and years where similar gears were used. Overall, American eel catch per unit effort (CPUE) in Quebec was stable whereas in Nova Scotia and PEI catches constantly increased since 1999. While these data are valuable in population estimation, fishery reports have not been implemented in all management RPA zones and are sometimes incomplete.

3.2.2. Fishery-independent indices

3.2.2.1. St. Lawrence Basin (SLB)

3.2.2.1.1. Bay of Quinte – Bottom trawl survey

The conditional part of the Bay of Quinte final model included year, month, depth and site, while the zero-inflated part included temperature and depth (AIC=2146; Table 9). All variables were significant, except depth in the conditional part of the model, and no residuals patterns or outliers were observed, suggesting that the model fit the data well (Fig. 12). The abundance index (1.42±0.47 eels trawl^{-1}) and the nominal index (1.86±0.54 eels trawl^{-1}) dropped sharply from 1972 to 2017 (Table 10; Fig. 13), reaching zero catches from 2003 to 2012. A slight increase was observed since 2012, which is probably due to eels which were introduced to the system by a conservation stocking program (Cairns 2020). Despite this increase, indices remained low (0.03 ±0.02 eels trawl^{-1}, 0.06±0.05 eels trawl^{-1}). Overall, abundance indices in Bay of Quinte indicated a decrease in American eel since 1975 in this region.

3.2.2.1.2. Moses-Saunders Dam – Pass survey

Data from the Saunders ladder of the Moses-Saunders Dam were divided in two datasets, for the periods 1974-1995 and 2006-2016.

Moses-Saunders datasets were used to develop different models. Overall, two zero-inflated GLMMs were similar (Table 9) and the model retaining all significant variables was considered as the final model. Month and temperature were included in the conditional part of the model while month and water level were included in the zero-inflated part (AIC= 34384). No pattern was detected in the residual plots indicating that the model fit the data (Fig. 12). The abundance index (4265±721 eels per day) was higher than the nominal index (3480±419 eels per day). Both trends indicated than eel abundance decreased steeply since the 1980s reaching a minimum in 2017 (Table 11; Fig. 13). Moreover, size of the eels caught at Moses-Saunders was under 75 cm indicating that abundance indices are characteristic of yellow eel abundance (Fig. 14).

3.2.2.1.3. Beauharnois Dam – Pass surveys

The Beauharnois Dam surveys included two ladders, west and east. To account for potential count differences between the two passes, a variable pass was added as a factor in the models. The Beauharnois Dam model retained year, month, pass, temperature and flow in the conditional part of the model and month in the zero-inflated (AIC=26215; Table 9). All variables were significant and a slight deviation in the residuals was observed in the QQ plot (Fig. 15). Abundance indices (288±24 eels per day) and nominal indices (290±34 eels per day) were similar (Table 12). Trends in abundance were comparable between indices with a peak in 2005 followed by a constant decrease until 2016 (Fig. 16). Length frequency of American eel at Beauharnois Dam showed that only one fish was larger than 75 cm signifying that a majority of eels caught were yellow eels (Fig. 17).

3.2.2.1.4. Chambly Dam – Pass surveys

The final model for the Chambly Dam retained year, month, temperature, and flow (AIC=9277; Table 9) and all variables were significant except flow. No obvious patterns in the residual plots were detected (Fig. 15). Overall, the abundance index (18.07±2.66 eel d^{-1}) and the nominal index (17.64±3.56 eel d^{-1}) were similar but highly variable from 2004 to 2018 with maximum catches recorded in 2010 and 2016 (Table 13; Fig. 16). Size of American eel at Chambly Dam ranged from 18.1 cm to 78.2 cm; only one eel was larger than 75 cm indicating that abundance indices were representative of yellow eel abundance (Fig. 18).

3.2.2.1.5. Saint Nicolas – Trap surveys

During the downstream migration of American eel in fall, catches in the SLB were dominated by silver eels. Therefore, two models were developed to investigate the abundance of American eel in Saint Nicolas surveys. One model included the entire time series (May-October) to characterize the overall abundance of American eels (yellow and silver) and a second model was developed to reflect the abundance of silver eels only (September-October).

The overall final model retained year, month, temperature and flow in the conditional part of the model and temperature and flow in the zero-inflated part (AIC=28874; Table 9). All variables were significant and residual plots indicated that the model fitted the data (Fig. 15). Overall, nominal abundance indices and nominal indices were similar (0.95±0.10 eels per tidal cycle) and 0.88±0.11 eels per tidal cycle) and indicated a decrease in abundance since 2001 (Table 14; Fig. 16).

The conditional part of the final model reflecting silver eel abundance included year, month and temperature while temperature was included in the zero-inflated part (AIC = 16090; Table 9). In both parts of the model, variables were significant and no patterns were observed in the residual plot (Fig. 15). Nominal indices were higher than the abundance index (1.98±0.11 and 1.65±0.24 eels per tidal cycle) and similar downward trends were observed from 1975 to 2018 (Table 15; Fig. 16).

3.2.2.2. Scotia-Fundy (SF)

3.2.2.2.1. Naswhaak River – Electrofishing survey

The best model for the Nashwaak River included year and temperature in the conditional part of the model and month in the zero-inflated part (AIC = 2660; Table 16). All variables were significant and residual plots indicated that the model fitted the data (Fig. 19). Eel abundance and nominal indices were similar with 1.37±0.33 eels 100m^{-2} and 1.50±0.32 eels 100m^{-2}, respectively (Table 17; Fig. 20). Estimates of abundance in the earlier years were higher than in the most recent years indicating a decrease in abundance from 1987 to 1992, after which abundance has been fairly stable. Size of mature American eels in SF is about 60 cm (Jessop 2010). In the Nashwaah River, a majority of eel caught was less than 60 cm indicating that the index in this river represents yellow eel abundance (Figs. 21-22).

3.2.2.2.2. LaHave River – Electrofishing survey

The final model for LaHave River retained year, month and flow in the conditional part of the model and flow in the zero-inflated part (AIC=1489; Table 16). Except flow in the conditional part of the model, all variables were significant. No outliers or obvious patterns in the residual plots were observed denoting the good fit of the data (Fig. 19). Nominal and abundance indices were comparable (0.53±0.20 eels 100m^{-2} and 0.51±0.21 eels 100m^{-2}) and indicated that American eel abundance in LaHave River surveys ranged from no eel in 1998 and 2007 to over 1 eel 100m^{-2} in 1995. Overall, abundance was relatively stable over the 22 year period (Table 18; Fig. 20).

3.2.2.2.3. St. Marys River – Electrofishing survey

The conditional part of the final model of St. Marys River retained year, temperature and flow while the zero-inflated part retained temperature and flow (AIC=1921; Table 16). Only year was significant in the final model and residual plots indicated that the model fit the data (Fig. 19). The abundance index (2.29±0.52 eels 100m^{-2}) and the nominal index (2.51±0.57 eels 100m^{-2}) indicated that American eel decreased sharply from 1995 to 2000 before constantly staying at low abundance (0.47±0.19 eels 100m^{-2}) (Table 19; Fig. 20).

3.2.2.2.4. Regional level – large eels

Abundance indices in SF were built based on the first sweep of the three electrofishing sessions (Nashwaak River, LaHave River, St. Marys River). The final model retained all variables in the conditional part of the model and the zero-inflated part (AIC=5984, Table 16). All variables were significant except for month in the zero-inflated part of the model and a significant deviation was detected in the residual plot (Fig. 19). Abundance indices revealed that American eel abundance in SF decreased from 1995 to 2000 (Table 20; Fig. 20) and remained constant over the last fifteen years.

3.2.2.2.5. Elvers – Trap survey

Tide and lunar phase (Thieurmel and Elmarhraoui 2019) were also included in the East River Chester full model as these variables have been described as major variables affecting elver runs in this region (Jessop 2003, 2010). We note that inclusion of lunar phase with tide height introduces collinearity because tide height is substantially governed by lunar phase (model effect for lunar phase is much less than for tide height). Because the number of zeros in this dataset was less than 1%, models were developed using a negative binomial distribution.

The final model included year, month, and tide (AIC = 4350; Table 21). No obvious patterns in the residual plots were observed and the final model provided an overall fit to the data (Fig. 23). Abundance indices and nominal indices were similar 285±66 per kg and 228±10 per kg, respectively (Table 22). Elver abundance was stable until 2015 before beginning a continuous increase to reach a maximum in 2018 (Fig. 24).

3.2.2.3. Southern Gulf of St. Lawrence (SG)

3.2.2.3.1. Restigouche River – Electrofishing survey

The final model for the Restigouche River included year, month, temperature, and flow in the conditional part of the model and month, temperature, and site in the zero-inflated part (AIC= 2959; Table 23). Only year and month were significant and no significant deviation was observed in the residual plot (Fig. 25). The abundance index (0.46±0.29 eels $100m^{-2}$) and the nominal index (0.55±0.28 eels $100m^{-2}$) were similar (Table 24), nevertheless trends were comparable from 1972 to 2018. Overall, American eel abundance was lowest during the early years of the time series, to increase from 1997 to 2007 then to slightly decrease until 2018 (Fig. 26).

3.2.2.3.2. Miramichi River – Electrofishing survey

The Miramichi River final model retained year, flow, and temperature in the conditional part of the model and temperature, flow and site in the zero-inflated part (AIC=7750; Table 23). This model was selected because the residual plot indicated that it better fitted the data (Fig. 25). The model predicted similar abundances (0.59±0.31 eels $100m^{-2}$) to the nominal index (0.66±0.26 eels $100m^{-2}$) (Table 25). Both indices were variable and similar trends were observed and indicated that American eel abundance was relatively stable over the last 40 years (Fig. 26).

3.2.2.3.3. Regional level

To determine the evolution of American eel abundance in SG, models including Restigouche River and Miramichi River electrofishing surveys were developed. The final model retained all variables in the conditional and zero-inflated part of the model (AIC=10012; Table 23). Except for month, all variables were significant and no obvious patterns were detected in the residual plot (Fig. 25). The abundance and nominal indices were similar with 0.63±0.23 eels $100m^{-2}$ and 0.64±0.24 eels $100m^{-2}$, respectively (Table 26). Overall, indices indicated that yellow eel abundance in SG was relatively stable since 1972 but at low abundance (Fig. 26).

3.2.2.4. Northern Gulf (NG)

3.2.2.4.1. Sud-Ouest River – Trap survey

The final model for Sud-Ouest River retained year, month, temperature, and flow in both parts of the model (AIC=5378; Table 27). No obvious patterns in the residual plots were detected (Fig 27). Similar trends were observed between the abundance index (11.72±2.88 eels per day) and the nominal index (11.57±2.64 eels per day) from 1999-2016; however, the model predicted an important catch of American eel in 2010 (57.15±12.86 eel eels per day) compared to the nominal index (34.37±6.78 eels per day) (Table 28; Fig. 28). Since 2010, American eel abundance indices have remained steady. A majority of American eel caught in Sud-Ouest surveys were less than 60 cm (Fig. 29) and under 10 years (Fig. 30) indicating that this time series represents yellow eel abundance.

3.2.2.5. Abundance indices summary

Twelve fishery-independent surveys were developed into abundance indices of American eel with time series ranging from 15 to 67 years. Index values were highly variable among surveys. Nine abundance indices were representative of yellow eel abundance and revealed that yellow eel abundance in most of the surveys declined in the early years of the time series and then remained constant or increased in recent years. Silver phase eel surveys in SLB indicated a decrease in American eel which could potentially indicate a decrease in spawning biomass produced in this zone. The abundance index from the single available elver survey indicated rising abundance since 2015.

To investigate the relationships among abundance indices from fisheries-independent surveys, a Spearman correlation matrix was developed (Fig. 31). Most of the abundance indices were correlated to another survey (r>0.5). The correlation matrix also indicated that Bay of Quinte and Moses-Saunders indices were highly correlated (r>0.7) with several surveys in SLB and SF suggesting that the changes in abundance in these zones might be related to the abundance of American eel in other zones.

3.3. POWER ANALYSIS

Power analysis values gave information on standardized abundance indices of fisheries-independent survey precision. Median CVs ranged from 0.08 to 0.62 and power values ranged from 0.03 to 1 (Table 29). Surveys with lower CVs had higher power than those with high CVs. In all power analysis tests, power to detect a 50% decrease was greater than power to detect a 50% increase. While regional indices for SF, Saint Nicolas, Beauharnois and Chambly Dam surveys power values were greater than 0.80, power values were relatively low for remaining surveys indicating that the ability to detect trends in the past 10 years was limited in this assessment.

3.4. TEMPORAL TRENDS

3.4.1. Lawrence Basin (SLB)

Despite the slight increase in American eel abundance observed since 2012 in the Bay of Quinte (probably due to stocked eels) a Mann-Kendall test detected a significant decrease in abundance in this region from 1975 to 2018. Similar results were observed for the Saint Nicolas survey with a decrease in abundance from 1975 to 2018; however, the magnitude of the slope was much less in Saint Nicolas indicating that the decline in American eel at this location was less important than in the Bay of Quinte (Table 30).

3.4.2. Scotia-Fundy (SF)

Trends in abundance for three surveys were investigated for SF. When all the surveys were included, American eel abundance appeared to be stable over the last 22 years although the trend in abundance was not significant in this zone. When the surveys were considered at a local scale, eel abundance in the Nashwaak River showed a significant decrease while the trends in LaHave and St. Marys Rivers were non-significant (Table 30). Moreover, the elver abundance index showed a significant increase.

3.4.3. Southern Gulf of St. Lawrence (SG)

Overall, Mann-Kendall indices indicated no significant trend in abundance in SG. Locally, Restigouche River indices presented a significant upward trend while no significant trend was detected for the Miramichi River (Table 30).

3.4.4. Northern Gulf of St. Lawrence (NG)

Only one survey was included in NG-NL and abundance trends in Sud-Ouest River were positive but not significant (Table 30).

3.4.5. Temporal trends summary

Seven statistically significant temporal trends were detected among the indices evaluated (Table 30). Moses-Saunders, Bay of Quinte, Saint Nicolas surveys and Nashwaak River exhibited significant downward trends over the time series while the Restigouche River and elver surveys showed significant upward trends. No other significant trends were detected.

3.5. AUTOREGRESSIVE INTEGRATED MOVING AVERAGE (ARIMA) AND FORECAST OF TRENDS IN ABUNDANCE

The final ARIMA models were fitted to the abundance indices of American eel for 10 surveys (Table 31). Autocorrelation (AC) and partial autocorrelation (PAC) functions were estimated to build ARIMA models to explain the time series and forecast the future abundance of American eel in Canada. The LjungBox test indicated no significant autocorrelation for the models tested (Table 31). Moreover, residuals from ARIMA model fits and forecast error plots showed that the variance of the forecast error is constant over time and was normally distributed indicating that the models tested for all regions provide accurate predictive models for American eel abundance.

3.5.1. St. Lawrence Basin (SLB)

SLB was the only region where several abundance indices steady declined since the 1970s. The most remarkable decline was observed in the Bay of Quinte where American eel abundance constantly decreased from 1972 through 2010 before rising through 2017. The decrease in the early years of the time series then the increase in most recent years was reflected in the variation of the probability of being less than the 25th percentile reference point observed over the time series (Table 31). Despite this increase, the ARIMA model forecast that the abundance would be low compared to earlier years but stable in the next ten years.

In the Quebec portion of the St. Lawrence Basin, ARIMA models predicted that American eel abundance will decrease at Saint Nicolas and Beauharnois Dam but will increase at Chambly Dam (Fig. 32). At Saint Nicolas and Beauharnois Dams, the probability of being less than 25th of percentile reference point in the final year index indicated a decrease of abundance over the last five years (Table 31).

Overall in the SLB region, abundance indices were predicted to be stable but at a low level in the next ten years (Fig. 32).

3.5.2. Scotia-Fundy (SF)

The fitted indices decreased until 2012 indicating a decreasing trend in abundance in the Nashwaak River, LaHave River and St. Marys River in the early years of the time series (Fig. 33; Table 31). Since 2012, LaHave River exhibited a steady trend while American eel abundance in the Nashwaak River and the St. Marys River increased over the last five years of the time series (Fig. 33). These results are supported by the decrease of 25th percentile reference point between 2012 and the final year for Nashwaak River and St. Marys River surveys (Table 31). Overall, the predictive models indicated that American eel abundance in SF will be constant in the next ten years.

3.5.3. Southern Gulf of St. Lawrence (SG)

In SG, abundance in Restigouche River was variable reaching a minimum early 1996 before increasing and remaining stable (Fig. 34). The index of probabilities decreased from 1977 to 2012 (0.18 to 0.05) and remained constant between the final and the reference year suggesting that abundance indices were stable over the last 5 years. In contrast, a large variation in probability was observed in Miramichi River. Probability of being less than the 25th percentile reference point increased in Miramichi River (0.12-0.18) indicating that the abundance indices in this area declined over the last 67 years.

Moreover, the ARIMA model forecast over the next ten years suggested that American eel abundance would be stable in the Miramichi River and slightly decreasing in the Restigouche River.

3.5.4. Northern Gulf of St. Lawrence

Abundance of American eel in the Sud-Ouest River was steady (Fig. 35). The index of probabilities remained relatively constant between the final and the reference year suggesting that abundance indices were stable (Table 31). A slight increase was observed since 2012 and prediction indicated that abundance in the next 10 years will be stable (Fig. 35).

3.5.5. ARIMA models summary

Trends in fitted abundance indices from ARIMA models showed much variation among surveys. The terminal year index values were above the 25th percentile of their respective time series, except for Chambly Dam and the Restigouche River (Table 31). When abbreviating surveys to a reference point, the terminal year of five indices were above the 25th percentile of the time series (Table 31). In general, the 25th percentile reference point provides information on abundance index trends and general indication of stock status; however, they are sensitive to the length and initial year of the time series. Because removing years of data can increase or decrease the probability of the terminal year being above the index, interpretation of change in status as a function of initial survey year can be misleading. Therefore, when more data are included in a time series with increases and decreases in abundance the 25th percentile may remain fairly constant while a time series with a constant trend in abundance would most likely have a variation in the 25th percentile.

4. DISCUSSION

4.1. LANDINGS

American eel fisheries were dominated by Canadian and American landings. Overall landings of large eels were highly variable with maximum landings in 1979 (2931 tons) followed by a constant decrease until the 2000s after which there was stability until today. In contrast, elver landings increased over the last decades to reach a maximum in 2013 (28.8 tons). Commercial activities are often described as a major factor impacting American eel abundance since different life stages are exploited which may produce high cumulative mortality (Castonguay et al. 1994). However, several factors are known to influence landings such as trade, economic considerations, and fisheries management measures. American eel fisheries activities are strongly connected to worldwide demand and the price of exported eel (i.e. US$250/kg to 1400/kg for elvers from 2014 to 2016) and international trade can explain some of the dynamics of eel landings (Gollock al. 2018). Moreover, the marked decrease in landings after 1979 heightened concerns about American eel conservation. Since 1979, various management restrictions have been implemented in North America including fishing bans and quotas, which potentially affected eel landings and contribute to explaining the decline observed in recent years. Apart from North America, commercial fisheries in the Caribbean Basin are fairly new and not related to long-standing cultural practices. Recently, high demand for seedstock in the Asian aquaculture industry has prompted the development of elver fisheries in islands of the northeastern Caribbean Basin. High prices have also encouraged illegal fishing and smuggling (Gollock al. 2018). American eel elvers from the Caribbean often transit through Canada and the US. It is difficult to determine the value of American eel exploited by each country, which makes the evaluation of American eel population over its range of distribution more challenging. Therefore, the overall decline of American eel landings observed since 1979 is most likely due to a combination of factors and the dynamics of American eel landings might not reflect species abundance. This highlights the difficulty in determining how fisheries removals of early stages (glass eels, elvers) and pre-spawning and spawning biomass (large eels) impact American eel populations

Annual commercial landings can give a misleading impression of stock trends when fishing is concentrated in a region where catches were initially high then declined rapidly because of high fishing effort. American eel landings in Canada show important regional fluctuations over time with high catches in the St. Lawrence Basin (SLB) until 1990, followed by a steady drop to 2016. Commercial fisheries data in SLB are available starting in 1870 and were encouraged up to 1970 by higher prices due to the expanding demand for eel (Eales 1968; Verreault et al. 2012). Declines in abundance after 1970 raised concerns for the long-term sustainability of the species resulting in stricter fishing regulations over the last decades, which have contributed to the landings decline in SLB. In Ontario commercial fisheries have been closed since 2004 while in Quebec a licence buy-back program was implemented in the early 2000s. Following licence buy-backs, silver eel fisheries decreased by 48% in the St. Lawrence estuary resulting in a decrease of the exploitation rate from 21.5% in the 1990s to 9.2% in 2008. Because SLB has been a large contributor to American eel landings, fishing regulations in this region have impacted overall Canadian landings over the last 20 years. However, regional fishery activities cannot fully explain the large fluctuations in landings observed since 1984 and other external forcing factors (habitat fragmentation, pollution, species introductions) may be partly responsible for these fluctuations.

4.2. FISHERY-DEPENDENT ABUNDANCE INDICES

While landings provide information on fisheries dynamics, they do not provide a reliable estimate of catchability related to population abundance (Maunder and Piner 2014). Catch and effort can be assigned to subregions occupied by American eel to estimate population abundance under different fishing pressures. Logbook records from the St. Lawrence estuary (SLB), Nova Scotia (SG), and Prince Edward Island (SG) provided information on four specific fisheries where trends in American eel diverged over the last two decades. CPUE decreased in Quebec while it increased in Gulf Nova Scotia and PEI reflecting the overall trends observed in landings in the SLB and SG regions. The high exploitation of American eel over 80 years in SLB might impact eel populations by affecting their recruitment (Robitaille et al. 2003). This, added to the management measures that decreased the number of fishing licences in Quebec since 2009, may explain the decline in catches observed in St. Lawrence estuary fisheries.

In contrast, the Gulf of St. Lawrence supports significant yellow eel fisheries and the CPUE in Gulf Nova Scotia increased over the last 20 years. This result suggests that the current situation of American eel stock in Canada might not be as critical as previously described when compared to the maximum year of exploitation (1971) during which SLB fisheries dominated Canadian landings. Moreover, long-term and short-term fluctuations in catches in Quebec, Nova Scotia, and PEI might be due to changes in fishing effort as well as changes in environmental conditions (temperature and flow) that might affect eel catchability (Castonguay et al. 1994; Cairns et al. 2007). Still, the lack of information on American eel biology and how they respond to environmental change makes it difficult to separate the roles of different factors (habitat conditions, human activities) in influencing American eel catches. Because American eel is a panmictic species and its population might not decrease at the same degree in all regions, fisheries activities need to be monitored to ensure that the American eel stock is not exploited beyond its ecological limit.

4.3. FISHERY-INDEPENDENT ABUNDANCE INDICES

Declining or neutral trends in American eel relative abundance were observed from 1952 to 2018 in Canada. While the power analysis results can be misleading as negative trends are more detectable than positive trends, Mann-Kendall tests and ARIMA models detected similar results with several significant declining trends in abundance indices. The most dramatic decline was observed in SLB. SLB is a major freshwater environment for American eel as juveniles (yellow eel) actively migrate upstream to reach Lake Ontario or settle in tidal zones of rivers until they reach maturity (silver eel) and start their migration back to the Sargasso Sea to spawn. Despite stocking programs and the cessation of fishing activities in 2004 in Lake Ontario, the current American eel population in the upper St. Lawrence-Lake Ontario is less than 1% of its historical level, suggesting a lack of eel recruitment in this area. Quebec long-term series indicate a decrease in American eel abundance in the St. Lawrence estuary; however, the decline in this region is not as great as that of Lake Ontario and recent surveys show that American eel abundance has been relatively stable since 2000. However, some American eel observed in the St. Lawrence estuary are derived from a stocking program that introduced over 4 million glass eels and elvers upstream of Moses-Saunders Dam (2005- 2010). Since 2009, stocked eels have been observed in the St. Lawrence estuary (Verreault et al. 2010) and represented nowadays one third of American eels leaving the St. Lawrence estuary to reach their spawning ground (Verreault and Dussureault 2018). Hence the increase in abundance indices observed over the last decade in the SLB most likely reflects the presence of stocked eels in the system rather than natural recruitment which is a concern for the recovery of American eel population. The near-absence of yellow eels in Lake Ontario and the lower abundance of yellow eel and silver eel in Quebec over the last decades suggest that the observed decline might have a substantial impact on the overall spawning biomass of American eels as yellow eel recruitment and silver eel contribute to a large portion of the breeding population. Habitat degradation (Chaput et al. 2014; Pratt et al. 2014; Belpaire et al. 2015) is often described as major factor influencing the distribution and abundance of American eel; it is therefore essential to better understand the influence of habitat suitability on migration and survival of American eel to support recruitment recovery. Apart from SLB, indices in SF and SG also indicate interannual variability in American eel abundance. Overall, trends were relatively steady but at low abundance in these areas.

Significant downward trends were observed in several surveys across Canada which is consistent with the previous assessment (Cairns et al. 2014); however, it is possible that trends in eel abundance may be caused by environmental changes due to factors not included in our models. Development of monitoring surveys in estuarine and coastal habitat will provide essential information on habitat use and population parameters relative to a specific environment which will improve predictive capabilities in the models.

4.4. STOCK STATUS DETERMINATION

American eel stock status was not determined in this assessment using stock assessment models therefore no reference points are proposed. For this assessment, quantitative stock status was determined via the probability that the terminal year of the indices for a given zone was greater than the index values from the start of the last assessment in 2012 (ARIMA analysis). Trend analyses were updated and were very similar to the results from the previous assessment (Cairns et al. 2014); therefore, the American eel stock remains threatened.

5. CONCLUSIONS

Abundance indices were highly variable among surveys and trends were very similar to those reported by Cairns et al. (2014). Trend analysis of most indices exhibited either no significant trend or decreasing trends, suggesting stable or decreasing populations of American eel. Overall, abundance was relatively low in SF and SG while the decrease in abundance and the failure to recover despite the reduction in fishing pressure is a concern for the management of the stock in SLB. Moreover, data coverage was not sufficient to fully characterize American eel abundance in Canada, especially in NG-NL. Despite some gaps, a large amount of data were gathered by different organizations over the last decades in many locations and zones. However, the lack of coordination among organizations can be an impediment to assessment of the American eel population. During the last two years, the Canadian American eel working group gathered and centralized datasets. While the processing time to collect the datasets and develop models did not allow us to present stock assessment models to provide reference points in this report, abundance indices and landings data are now available to be included in stock assessment models.

Since population dynamics and environmental changes can have major impacts on stock recovery and expected time of rebuilding, the lack of information on life stage and habitat use of American eel associated with fishery-dependent and -independent surveys limits our ability to fully estimate American eel stock abundance. Abundance indices were able to capture the underlying population trends of American eel in Canada and indicated environmental conditions generated fluctuations in abundance in space and time but the absence of information on habitat requirements of American eel in freshwater, estuarine, and coastal habitats generates some uncertainty in the evaluation of its population.

The incomplete coverage of fishery-independent and -dependent data across the American eel's Canadian range, and the uncertainty in the data impede the ability to make strong quantitative conclusions on the overall American eel population in Canada. The American eel stock is still considered as threated in Canada; therefore, it is essential to continue to monitor American eel to gather information on this species and restore its population.

6. RESEARCH RECOMMENDATIONS

- Expand and improve the genetic stock definitions of American eel to characterize population structure across its distribution range.
- Establish regional fishery-independent surveys to estimate silver eel, yellow eel and elver relative abundance to create reliable indices of abundance that reflect the status of different life stages.
- Determine habitat use by life history stage in freshwater, estuarine, and marine environments.
- Investigate the influence of environmental conditions on American eel, including the effects on movement, spawning, and survival.
- Collect life history information (e.g., age, growth, fecundity, maturity, spawning frequency).
- Determine the impact of habitat fragmentation on migration and survival of American eel.
- Continue and improve monitoring of commercial fisheries to collect more detailed information on type of gear, fishing locations, etc.
- Establish recovery goals and resilience of American eel to measure progress and development of its population.
- Implement direct monitoring of American eel that is designed to support assessments at local and regional levels and/or expand existing regional surveys.
- Improve quantitative methods to provide reference points.
- Encourage data management and data sharing procedures to use all available American eel data.
- Promote greater international data sharing, cooperative research, and monitoring.

ACKNOWLEDGEMENTS

We thank the many people involved over the years in American eel research who have contributed to its stock assessment report. Thank you to the research group and panel of experts that provided valuable advice to develop this report.

REFERENCES CITED

ASMFC (Atlantic States Marine Fisheries Commission). 2017. American eel stock assessment update. Atlantic States Marine Fisheries Commission, Washington.

Bai J., Perron P. 2003. Computation and analysis of multiple structural change models. Journal of Applied Econometrics 18:1–22.

Belpaire C., Pujolar J.M., Geeraerts C., Maes G.E. 2015. Contaminants in eels and their role in the collapse of the eel stocks. Pp. 225-250. In T. Arai (ed.) Biology and Ecology of Anguillid eels, CRC Press, London.

Brooks M.E., Kristensen K., van Benthem K.J., Magnusson A., Berg C.W., Nielsen A., Skaug H.J., Maechler M., Bolker B.M. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated Generalized Linear Mixed Modeling. The R Journal, 9:378-400.

Cairns, D.K. 2020. Landings, abundance indicators, and biological data for a potential range-wide American eel stock assessment. Canadian Data Report of Fisheries and Aquatic Sciences No. 1311. 180 pp.

Cairns D.K., Castonguay M., Dumont P., Caron F., Verreault G., Mailhot Y. 2007. Why has the American eel, *Anguilla rostrata*, declined dramatically in the St. Lawrence River but not the Gulf? ICES Eel Working Group, ICES CM working paper.

Cairns D.K., Chaput G., Poirier L.A., Avery T.S., Castonguay M., Mathers A., Casselman J.M., Bradford R.G., Pratt T., Verreault G., Clarke K., Veinott G., Bernatchez L. 2014. Recovery Potential Assessment for the American eel (*Anguilla rostrata*) for eastern Canada: life history, distribution, reported landings, status indicators, and demographic parameters. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/134. xiv + 157 p.

Cairns D.K., Tremblay V., Caron F., Casselman J.M., Verreault G., Jessop B.M, de Lafontaine Y, Bradford R.G., Verdon R., Dumont P, Mailhot Y, Zhu X., Mathers A., Oliveira K., Benhalima K, Dietrich J., Hallett J.A., Lagacé M. 2009. American eel abundance indicators in Canada. Canadian Data Report of Fisheries and Aquatic Sciences. No. 1207. 78 pp.

Casselman J.M. 2003. Dynamics of resources of the American eel, *Anguilla rostrata*: declining abundance in the 1990s. Pp. 255–274 in K. Aida, K. Tsukamoto and K. Yamauchi (eds.). Eel Biology, Springer-Verlag, Tokyo.

Castonguay M., Hodson P.V., Couillard C.M., Eckersley M.J., Dutil J.-D., Verreault G., 1994. Why is recruitment of the American eel, *Anguilla rostrata*, declining in the St. Lawrence River and Gulf? Canadian Journal of Fisheries and Aquatic Sciences 51:479–488.

Chaput G., Cairns D.K., Bastien-Daigle S., LeBlanc C., Robichaud L., Turple J., Girard C. 2014a. Recovery Potential Assessment for the American eel (*Anguilla rostrata*) for eastern Canada: mitigation options. Can. Sci. Advis. Sec. Res. Doc. 2013/133. v + 30 p.

Chaput G., Pratt T.C, Cairns D.K., Clarke K.D., Bradford R.G, Mathers A., Verreault G. 2014b. Recovery Potential Assessment for the American eel (*Anguilla rostrata*) for eastern Canada: description and quantification of threats. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/135. vi + 90 p.

COSEWIC. 2012. Assessment and status report on the American eel *Anguilla rostrata* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa. 109 pp.

DFO. 2014. Recovery Potential Assessment of American eel (*Anguilla rostrata*) in eastern Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/078.

DFO. 2017. Proceedings of the Regional Peer Review of the Stock Framework for American Eel (*Anguilla rostrata*) and Elvers; October 26-27, 2016. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2017/048.

DFO. 2019. Assessment of the Maritimes Region American Eel and Elver Fisheries. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/054.

Eales J.G. 1968. The eel fisheries of Eastern Canada. Fisheries Research Board of Canada Bulletin 166:79.

Fogarty M.J., Miller T.J. 2004. Impact of a change in reporting systems in the Maryland blue crab fishery. Fisheries Research 68:37–43.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology 68:1364–1372.

Gilbert, R.O. 1987. Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York. 320 pp.

Gollock M., Shiraishi H., Carrizo S., Crook V., Levy E. 2018. Status of non-CITES listed anguillid eels. Zoological Society of London. 193 pp.

Hamed, K.H., Rao A.R. 1998. A modified Mann-Kendall trend test for autocorrelated data. Journal of Hydrology 204:182-196.

Harley S.J., Myers R.A., Dunn A. 2001. Is catch-per-unit-effort proportional to abundance? Canadian Journal of Fisheries and Aquatic Sciences 58:1760–1772.

Hartig F. 2019. DHARMa: residual diagnostics for hierarchical (multi-level / mixed) regression models. R package version 0.2.0.

Helser T.E., Hayes D.B. 1995. Providing quantitative management advice from stock abundance indices based on research surveys. Fishery Bulletin 93:290–298.

Hilborn R., Walters C.J. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York. 570 pp.

Hyndman R., Athanasopoulos G., Bergmeir C., Caceres G., Chhay L., O'Hara-Wild M., Petropoulos F., Razbash S., Wang E., Yasmeen F. 2019. Forecast: forecasting functions for time series and linear models. R package version 8.7.55.

Jessop B.M. 2003. The run size and biological characteristics of American eel elvers in the East River, Chester, Nova Scotia, 2000. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2444.

Jessop B.M. 2010. Geographic effects on American eel (*Anguilla rostrata*) life history characteristics and strategies. Canadian Journal of Fisheries and Aquatic Sciences 67:326-346.

Kim J.Y., Jeong H.C., Kim H., Kang S. 2015. Forecasting the monthly abundance of anchovies in the South Sea of Korea using a univariate approach. Fisheries Research 161:293-302.

Lüdecke D. 2019. sjstats: statistical functions for regression models. R package version 0.17.5.

Maunder M.N., Piner K.R. 2014. Contemporary fisheries stock assessment: many issues still remain. ICES Journal of Marine Science 72:7–18.

Nelson G.A. 2018. fishmethods: fishery science methods and models. R package version 1.11-0.

Patakamuri S.K., O'Brien N. 2019. modifiedmk: modified versions of Mann Kendall and Spearman's Rho trend tests. R package version 1.4.0.

Pratt T.C., Bradford R.G., Cairns D.K., Castonguay M., Chaput G., Clarke K.D., Mathers A. 2014. Recovery Potential Assessment for the American eel (*Anguilla rostrata*) in eastern Canada: functional description of habitat. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/132. v + 49 pp.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

Robitaille J.A., Bérubé P., Tremblay S., Verreault, G. 2003. Eel fishing in the Great Lakes/St. Lawrence River system during the 20th century: signs of overfishing. Pp. 253-262 in D.A. Dixon (ed.). Biology, management, and protection of catadromous eels. American Fisheries Society Symposium No. 33.

Thibault I., Dodson J.J., Caron F., Tzeng W.-N., Iizuka I., Shiao, J.-C. 2007. Facultative catadromy in American eels: testing the conditional strategy hypothesis. Marine Ecology Progress Series 344:219-229.

Thieurmel B., Elmarhraoui A. 2019. suncalc: compute sun position, sunlight phases, moon position and lunar phase. R package version 0.5.0.

Verreault G., Dumont P., Dussureault J., Tardif R. 2010. First record of migrating American eels (*Anguilla rostrata*) in the St. Lawrence Estuary originating from a stocking program. Journal of Great Lakes Research 36:794-797.

Verreault G., Dussureault J. 2018. Estimation de l'abondance et des caractéristiques des anguilles d'Amérique provenant des ensemencements dans la pêcherie de l'estuaire du Saint-Laurent en 2018. Ministère des Forêts, de la Faune et des Parcs, Direction de la gestion de la faune du Bas-Saint-Laurent. 23 pp.

Verreault G., Mingelbier M., Dumont P. 2012. Spawning migration of American eel *Anguilla rostrata* from pristine (1843-1872) to contemporary (1963-1990) periods in the St Lawrence estuary, Canada. Journal of Fish Biology 81:387-407.

Walters, C. 2003. Folly and fantasy in the analysis of spatial catch rate data. Canadian Journal of Fisheries and Aquatic Sciences 60:1433–1436.

Zeileis A., Kleiber C., Krämer W., Hornik K. 2003. Testing and dating of structural changes in practice. Computational Statistics and Data Analysis 44:109–123.

Zeileis A., Leisch F., Hornik K., Kleiber C., Hansen B. 2015. strucchange: testing, monitoring, and dating structural changes.

TABLES

Table 1. Datasets reviewed and included in the stock assessment report to develop abundance indices for American eel in Prince Edward Island (PEI), Nova Scotia (NS), Quebec (QC), Newfoundland (NL), and Ontario (ON).

Survey considered			Decision		Reason (s)			
Type	**Province**	**Fishery/Site**	**Accepted**	**Rejected**	**Time series too short or discontinued**	**Unusable (CSAS I)**	**Limited covariate**	**Incomplete or unavailable**
Fishery-dependent	**PEI**	**Fyke net**	×	-	-	-	-	-
	NS	**Fyke net**	×	-	-	-	-	-
	NS	**Spear net**	×	-	-	-	-	-
	QC	**Trap net**	×	-	-	-	-	-
	QC	**St. Lawrence CMR**	-	×	-	-	-	-
	QC	**St. Romuald**	-	×	-	×	×	×
Fishery-independent	**NL**	**Western Arm Brook**	-	×	-	×	-	-
	NL	**Conne River**	-	×	-	×	-	-
	NB	**Miramichi River**	×	-	-	-	-	-
	NB	**Restigouche River**	×	-	-	-	-	-
	NS	**St. Mary`s River**	×	-	-	-	-	-
	NS	**East River Chester**	×	-	-	-	-	-
	NS	**LaHave River**	×	-	-	-	-	-
	NS	**Big Salmon River**	-	×	×	-	-	-
	NS	**Nashwaak River**	×	-	-	-	-	-
	QC	**Sud-Ouest River**	×	-	-	-	-	-
	QC	**Saint Nicolas**	×	-	-	-	-	-
	QC	**Levis**	-	×	-	×	×	×
	QC	**Chambly Dam**	×	-	-	-	-	-
	QC	**Beauharnois Dam**	×	-	-	-	-	-
	QC	**Douville**	-	×	×	-	-	×
	ON	**Bay of Quinte**	×	-	-	-	-	-
	ON	**Moses-Saunders Dam**	×	-	-	-	-	-

Table 2. Fishery-dependent and -independent surveys used to develop abundance indices for American eel in the St. Lawrence Basin (SLB), Scotia-Fundy (SF), Southern Gulf of St. Lawrence (SG), and Northern Gulf of St. Lawrence and Newfoundland (NG-NL).

Type survey	Zones	Fishery / Survey	Life stage	Habitat	Gear	Years	Months
Fishery-Dependent	**SLB**	**Lower St. Lawrence**	Silver	Freshwater	Trap	1996-2017	7, 8 ,9, 10, 11
	SG	**Spear fishery (NS)**	Yellow	Estuary/Marine	Spear	1998-2018	1, 2, 3, 4
	SG	**Fyke fishery (NS)**	Yellow	Estuary/Marine	Fyke net	1997-2018	9, 10
	SG	**Fyke fishery (PEI)**	Yellow	Estuary/Marine	Fyke net	1996-2018	8, 9, 10
Fishery-Independent	**SLB**	**Bay of Quinte**	Yellow	Freshwater	Trawl	1972-2017	5, 6, 7, 8, 9
	SLB	**Saint Nicolas**	Silver-Yellow	Freshwater	Trap	1975-2014	6,7, 8, 9,10
	SLB	**Chambly Dam**	Yellow	Freshwater	Pass	2004-2018	6, 7, 8, 9
	SLB	**Beauharnois Dam**	Yellow	Freshwater	Pass	2002-2018	6, 7, 8, 9, 10
	SLB	**Moses Dam**	Yellow	Freshwater	Pass	1974-1996	6, 7, 8, 9, 10
	SLB	**Saunders Dam**	Yellow	Freshwater	Pass	2006-2016	6, 7, 8, 9, 10
	SF	**LaHave**	Yellow	Freshwater	Electrofishing	1995-2017	7, 8, 9
	SF	**St Mary`s**	Yellow	Freshwater	Electrofishing	1995-2017	7, 8, 9
	SF	**Nashwaak**	Yellow	Freshwater	Electrofishing	1987-2018	7, 8, 9
	SF	**East Chester River**	Elvers	Freshwater	Trap	1995-2018	4, 5, 6, 7, 8
	SG	**Miramichi**	Yellow	Freshwater	Electrofishing	1952-2018	6, 7, 8, 9, 10
	SG	**Restigouche**	Yellow	Freshwater	Electrofishing	1972-2018	7, 8, 9,10
	NG	**Sud-Ouest**	Yellow	Freshwater	Trap	1999-2016	6, 7, 8

Table 3. Variable types used to standardize abundance indices.

Variables	Type
Year	Factor
Month	Factor
Temperature	Continuous
log(Flow)	Continuous
Depth	Continuous
Site	Factor
Area	Continuous
Soak time	Continuous

Table 4. Nominal abundance indices for American eel in the St. Lawrence estuary (kg per m).

Year	Nominal index
1996	4.67
1997	4.24
1998	5.68
1999	5.08
2000	5.93
2001	5.97
2002	6.67
2003	5.65
2004	6.40
2005	6.58
2006	6.85
2007	5.86
2008	4.71
2009	4.12
2010	4.99
2011	3.72
2012	3.52
2013	3.00
2014	3.89
2015	3.36

Table 5. Model selection for fishery-dependent abundance indices in Nova Scotia (NS) and Prince Edward Island (PEI) using negative binomial (NB) GLM. Delta corrected Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error *(rmse), statistical significance of the variables tested *p < 0.05, **p=0.01, ***p < 0.01.*

a) Spear NS

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse
~ Year*** + Month*** + Fishermen*** + offset(log(hours)	~ 0	0	NB	0.11	<0.01	17.7
~ Year*** + Month*** + Fishermen*** + Temperature	~ 0	1.7	NB	0.23	<0.01	17.7
~ Year*** + Month*** + Fishermen *** + Flow + Temperature	~ 0	3.4	NB	0.29	<0.01	17.7

b) Fyke net NS

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse
~ Year + Month + Fishermen * + offset(Soak time)	~ 0	0	NB	0.67	0.23	116.3
~ Year + Month + Temperature + offset(Soak time)	~ 0	2.5	NB	0.78	0.26	116.4
~ Year + Month + Temperature*** + Flow +offset(Soak time)	~ 0	4.6	NB	0.86	0.34	116.3

c) Fyke net PEI

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse
~ Year*** + Month* + Fishermen*** + offset(log(Trap))	~ 0	0	NB	0.00	<0.01	26.5
~ Year*** + Month*** + Fishermen*** + Temperature + offset(log(Trap))	~ 0	2.0	NB	0.00	<0.01	26.5
~ Year*** + Month*** + offset(log(Trap))	~ 0	2020.4	NB	0.00	<0.01	30.1

Table 6. Abundance indices calculated using a negative binomial model (NB) and nominal abundance indices for winter spear fishery (kg of legal sized eels per spear-hour) (Gulf Nova Scotia). SE represents the standard error of the mean and blank cells indicate missing data.

Year	NB		Nominal	
	Index	SE	Index	SE
1997	2.19	0.32	2.24	0.16
1998	2.24	0.29	2.42	0.36
1999	-	-	-	-
2000	1.97	0.27	2.01	0.35
2001	1.48	0.25	1.50	0.31
2002	3.31	0.48	3.34	0.31
2003	3.01	0.34	2.95	0.17
2004	3.08	0.43	3.25	0.32
2005	3.59	0.38	3.65	0.27
2006	4.51	0.48	4.50	0.40
2007	5.02	0.61	4.96	0.50
2008	5.72	0.62	5.48	0.43
2009	2.90	0.30	2.85	0.25
2010	4.55	0.55	4.40	0.53
2011	4.53	0.71	4.43	0.33
2012	4.76	0.58	4.93	0.77
2013	5.25	0.59	5.25	0.53
2014	5.16	0.52	5.34	0.44
2015	5.12	0.58	5.25	0.57
2016	8.39	1.01	8.31	0.92
2017	7.67	1.05	8.29	1.40
2018	8.90	1.24	8.96	1.06

Table 7. Abundance indices calculated using a negative binomial model (NB) and nominal abundance indices for the fyke net fishery (kg of legal sized eels per net per day) (Gulf Nova Scotia). SE represents the standard error of the mean.

Year	NB		Nominal	
	Index	SE	Index	SE
1997	2.14	0.77	1.93	0.68
1998	1.01	0.27	1.01	0.20
1999	1.21	0.24	1.20	0.20
2000	1.34	0.28	1.34	0.37
2001	1.27	0.27	1.29	0.34
2002	1.17	0.23	1.17	0.18
2003	1.72	0.58	1.70	0.38
2004	1.82	0.38	1.90	0.22
2005	2.32	0.36	2.34	0.24
2006	2.85	0.44	2.98	0.28
2007	3.01	0.48	2.94	0.34
2008	2.39	0.43	2.47	0.41
2009	3.18	0.51	3.13	0.33
2010	3.95	0.83	3.99	0.77
2011	2.42	0.39	2.39	0.32
2012	2.53	0.43	2.77	0.65
2013	1.46	0.24	1.53	0.46
2014	2.32	0.52	2.34	0.52
2015	4.02	0.98	4.07	1.09
2016	10.42	2.79	10.60	2.71
2017	6.93	1.67	6.98	2.61
2018	2.14	0.77	1.93	0.68

Table 8. Abundance indices calculated using a negative binomial model (NB) and nominal abundance indices for the fyke net fishery (kg of legal sized eels per net per day) (Prince Edward Island). SE represents the standard error of the mean.

Year	NB		Nominal	
	Index	SE	Index	SE
1996	0.52	1.38	0.24	0.01
1997	0.36	1.15	0.28	0.01
1998	0.46	1.90	0.60	0.04
1999	1.69	4.19	0.81	0.06
2000	1.94	4.02	1.06	0.06
2001	0.90	1.47	0.83	0.14
2002	1.52	2.17	0.86	0.05
2003	2.13	4.06	1.00	0.05
2004	2.82	5.67	1.53	0.17
2005	2.73	4.69	1.15	0.08
2006	2.49	4.26	0.86	0.04
2007	3.21	5.86	1.81	0.10
2008	3.06	5.77	1.76	0.11
2009	3.52	6.37	1.35	0.11
2010	2.59	4.38	1.55	0.10
2011	2.16	3.99	1.51	0.09
2012	2.71	4.39	1.69	0.07
2013	2.27	3.37	1.29	0.04
2014	2.83	4.79	2.25	0.15
2015	2.55	3.41	1.64	0.11
2016	2.91	3.67	1.63	0.16
2017	2.96	4.83	1.43	0.06
2018	1.75	4.12	1.25	0.05

Table 9. Model selection for the standardized abundance indices for St. Lawrence Basin (Ontario) for zero-inflated (ZINB) and negative binomial (NB) GLMMs. Delta corrected Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error *(*rmse*), statistical significance of the variables tested *p < 0.05, **p=0.001, ***p < 0.001.*

a) Bay of Quinte

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse	r^2 cond	r^2 marg
~ Year*** + Month*** + Depth + Site + offset (Area)	~ Temperature* + Depth**	0	ZINB	0.88	0.53	2.35	0.78	0.78
~ Year*** + Month*** + Site + offset (Area)	~ 0	5.3	NB	0.66	0.62	2.40	0.75	0.75
~ Year*** + Month*** + Depth + Water level + Site + offset (Area)	~ Temperature + Depth	5.9	ZINB	0.18	0.67	2.37	0.78	0.78
~ Year*** + Month*** + Depth + Temperature + Site + offset (Area)	~ Temperature + Depth	6.5	ZINB	0.40	0.68	2.37	0.61	064
~ Year*** + Month* + Temperature + Site + offset (Area)	~ 0	7.5	NB	0.30	0.62	2.40	0.75	0.75
~ Year*** + Month*** + Depth + Temperature + Water level + Site + offset (Area)	~ Temperature + Depth	8.0	ZINB	0.59	0.58	2.37	0.79	0.78
~ Year*** + Month*** + Depth + Temperature + Water level + Site + offset (Area)	~ Temperature + Depth + Water level	8.4	ZINB	0.49	0.62	2.37	0.78	0.78
~ Year*** + Month*** + Depth + Temperature + Site + offset (Area)	~ 0	9.5	NB	0.56	0.58	2.39	0.75	0.75
~ Year*** + Site + offset (Area)	~ 0	10.3	NB	0.29	0.70	2.40	NA	0.84
~ Year*** + Month* + Depth + Temperature + Water level + Site + offset (Area)	~ 0	11.0	NB	0.93	0.62	2.39	0.78	0.78

b) Moses-Saunders

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse
~ Year*** + Month*** + Temperature*** + Water level***	~ Month*** + Temperature Water level*	0	ZINB	0.19	<0.01	4541.81
~ Year*** + Month*** + Temperature*** + Water level***	~ Month*** + Water level***	0.4	ZINB	0.38	<0.01	4524.70
~ Year*** + Month*** + Temperature*** + Water level***	~ Month***	45.1	ZINB	0.27	<0.01	4615.70
~ Year*** + Month*** + Temperature***	~ Month***	61.8	ZINB	0.13	<0.01	4930.66
~ Year*** + Month*** + Temperature*** + Water level***	~ 1	158.0	ZINB	0.20	<0.01	4739.69
~ Year*** + Month*** + Temperature*** + Water Level***	~ 0	173.0	NB	0.14	<0.01	4817.27
~ Year*** + Month*** + Temperature***	~ 0	197.5	NB	0.11	<0.01	5209.47
~ Year*** + Month***	~ 0	207.7	NB	0.08	<0.01	4835.49
~ Year*** + Month*** + Water level***	~ 0	237.8	NB	0.05	<0.01	4523.42

c) Beauharnois

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse
~ Year*** + Month*** + Pass*** + Flow* + Temperature***	~ Month***	0	ZINB	0.01	0.07	326.13
~ Year*** + Month*** + Pass*** + Temperature***	~ Pass*** + Temp	1.5	ZINB	<0.01	0.07	324.31
~ Year*** + Month*** + Pass*** + Flow* + Temperature***	~ Month*** + Temp	2.0	ZINB	<0.01	0.08	326.12
~ Year*** + Month*** + Pass*** + Temperature***	~ Month***	2.3	ZINB	0.01	0.10	326.06
~ Year*** + Month*** + Pass*** + Temperature***	~ Month*** + Pass*** + Temp*	97.9	ZINB	<0.01	<0.01	336.37
~ Year*** + Month*** + Pass*** + Flow + Temperature***	~ 0	171.4	NB	<0.01	0.97	334.74
~ Year*** + Month*** + Pass*** + Temperature***	~ 0	172.5	NB	<0.01	0.88	334.65
~ Year*** + Month*** + Pass***	~ 0	443.4	NB	<0.01	0.71	373.27
~ Year*** + Month*** + Pass*** + Flow	~ 0	443.5	NB	<0.01	0.77	373.47

d) Chambly

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse
~ Year*** + Month*** + Temperature***	~ Month*** + Flow*** + Temperature***	0	ZINB	0.06	0.55	41.43
~ Year*** + Month*** + Flow + Temperature***	~ Month*** + Flow*** + Temperature***	0.2	ZINB	0.05	0.52	41.8
~ Year*** + Month*** + Flow + Temperature***	~ Month*** + Flow***	12.5	ZINB	0.05	0.37	41.18
~ Year*** + Month*** + Flow + Temperature***	~ Month*** + Temperature***	18.5	ZINB	0.04	0.60	41.72
~ Year*** + Month*** + Temperature***	~ Month***	31.6	ZINB	0.10	0.64	41.65
~ Year*** + Month*** + Flow + Temperature***	~ 0	86.5	NB	0.09	0.40	41.42
~ Year*** + Month*** + Temperature***	~ 0	87.1	NB	0.04	0.62	41.06
~ Year*** + Month*** + Flow**	~ 0	392.1	NB	<0.01	0.32	45.66
~ Year*** + Month***	~ 0	400.5	NB	<0.01	0.49	45.28

e) Saint Nicolas YE-SE

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse
~ Year*** + Month*** + Flow*** + Temperature*** + offset(Soak time)	~ Flow* + Temperature***	0	ZINB	0.07	<0.01	1.88
~ Year*** + Month*** + Flow*** + Temperature*** + offset(Soak time)	~ Temperature***	4.3	ZINB	0.01	0.01	1.88
~ Year*** + Month*** + Temperature*** + offset(Soak time)	~ Flow + Temperature***	22.8	ZINB	0.02	<0.01	1.88
~ Year*** + Month*** + Temperature*** + offset(Soak time)	~ Temperature***	23.8	ZINB	0.05	0.02	1.87
~ Year*** + Month*** + Flow*** + Temperature*** + offset(Soak time)	~ 1	167.8	ZINB	0.04	<0.01	1.90
~ Year*** + Month*** + Flow*** + offset(soak time)	~ 0	227.7	NB	0.05	<0.01	1.90
~ Year*** + Month*** + Flow*** + Temperature*** + offset(Soak time)	~ 0	228.0	NB	0.10	0.01	1.90
~ Year*** + Month*** + Temperature + offset(Soak time)	~ 0	239.8	NB	0.08	<0.01	1.90
~ Year*** + Month***	~ 0	240.8	NB	0.13	<0.01	1.90

f) Saint Nicolas SE

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse
~ Year*** + Month*** + Flow + Temperature*** + offset(soak time)	~ Temp*** + Flow	0	ZINB	0.01	<0.01	2.98
~ Year*** + Month*** + Temperature*** + offset(soak time)	~ Temp***	0.3	ZINB	0.06	0.02	2.99
~ Year*** + Month*** + Temperature*** + offset(soak time)	~ Temp*** + Flow	34.2	ZINB	0.05	<0.01	2.99
~ Year*** + Month*** + Flow + Temperature****	~ Temp*** + Flow	41.2	ZINB	0.03	0.01	2.99
~ Year*** + Temperature*** + offset(soak time)	~ Temp*** + Flow	42.9	ZINB	0.02	<0.01	2.99
~ Year*** + Month*** + Flow** + Temperature** + offset(soak time)	~ 0	95.7	NB	0.01	0.01	3.01
~ Year*** + Month*** + Flow* + offset(soak time)	~ 0	97.7	NB	<0.01	0.01	3.02
~ Year*** + Month*** + Temperature + offset(soak time)	~ 0	100.5	NB	<0.01	0.02	3.02
~ Year*** + Month*** + offset(soak time)	~ 0	101.0	NB	<0.02	0.02	3.02

Table 10. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for trawling surveys (eels trawl^{-1}) in the Bay of Quinte (St. Lawrence Basin). SE represents the standard error of the mean and blank cells indicate missing data. Note that the increase in the index starting in 2012 is probably due to stocked eels.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1972	9.13	2.84	8.78	2.05
1973	5.96	1.70	6.50	1.40
1974	4.77	1.38	5.16	1.56
1975	7.29	2.34	8.27	2.24
1976	4.36	1.23	6.50	1.51
1977	4.21	1.27	5.41	1.49
1978	0.92	0.33	1.37	0.34
1979	2.84	0.85	4.05	1.44
1980	0.58	0.24	0.77	0.24
1981	3.69	1.08	5.87	1.45
1982	-	-	4.17	1.20
1983	1.12	0.55	1.67	0.58
1984	0.59	0.32	0.97	0.40
1985	2.35	1.00	3.30	1.67
1986	3.47	1.71	3.47	1.49
1987	4.31	1.64	5.42	1.69
1988	0.58	0.20	0.87	0.24
1989	-	-	-	-
1990	0.58	0.17	1.09	0.25
1991	0.92	0.26	1.52	0.41
1992	1.19	0.30	2.34	0.71
1993	0.87	0.27	1.27	0.40
1994	1.31	0.38	4.25	0.82
1995	0.15	0.07	0.26	0.10
1996	0.43	0.14	1.22	0.37
1997	0.17	0.06	0.24	0.09
1998	0.18	0.06	0.28	0.08
1999	0.15	0.06	0.23	0.10
2000	0.10	0.05	0.17	0.10
2001	0.02	0.02	0.04	0.04
2002	0.05	0.04	0.09	0.06
2003	0.00	00.0	0.00	0.00
2004	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00
2006	0.00	0.00	0.00	0.00
2007	0.00	0.00	0.00	0.00
2008	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00
2011	0.00	0.00	0.00	0.00
2012	0.03	0.03	0.04	0.04
2013	0.03	0.03	0.04	0.04
2014	0.00	0.00	0.00	0.00
2015	0.02	0.03	0.05	0.05
2016	0.07	0.05	0.13	0.10
2017	0.05	0.04	0.13	0.07

Table 11. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices (eels per day) for fishway surveys in the Moses-Saunders Dam (St. Lawrence Basin). SE represents the standard error of the mean and blank cells indicate missing data.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1974	5909.23	1318.96	4270.54	537.43
1975	9938.60	3231.85	7960.62	1695.44
1976	6579.69	1740.94	5155.20	900.73
1977	-	-	-	-
1978	-	-	-	-
1979	14988.99	2045.39	9936.45	840.06
1980	11641.73	2343.49	7250.23	964.91
1981	10584.36	1340.25	7035.47	515.87
1982	9446.57	1187.45	10138.48	1231.29
1983	17614.56	2280.04	13909.35	995.97
1984	8198.67	1144.33	8633.07	771.93
1985	9533.09	1179.00	9080.78	784.72
1986	2567.13	330.09	2427.05	253.27
1987	6854.37	896.34	4185.39	352.35
1988	4233.42	672.22	3646.95	342.11
1989	3432.19	485.40	3310.59	334.96
1990	1467.51	214.89	1747.00	251.37
1991	565.65	89.58	659.00	111.50
1992	272.89	43.53	195.47	39.18
1993	314.50	67.57	259.42	53.31
1994	5196.22	1193.88	6056.33	1583.87
1995	1927.39	425.91	1131.48	311.61
1996	-	-	-	-
1997	-	-	-	-
1998	-	-	-	-
1999	-	-	-	-
2000	-	-	-	-
2001	-	-	-	-
2002	-	-	-	-
2003	-	-	-	-
2004	-	-	-	-
2005	-	-	-	-
2006	45.51	5.63	77.31	12.48
2007	19.59	2.45	19.21	3.90
2008	61.66	7.87	50.65	6.50
2009	10.64	1.35	14.99	2.70
2010	6.92	0.91	7.82	1.71
2011	96.61	11.85	94.50	12.51
2012	379.59	51.74	212.81	26.33
2013	101.46	12.10	159.10	21.43
2014	106.44	13.11	116.93	15.36
2015	80.85	9.74	101.48	13.38
2016	40.34	5.08	50.75	7.11

Table 12. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices (eels per day) for fishway surveys in the Beauharnois Dam (St. Lawrence Basin). SE represents the standard error of the mean.

Year	ZINB		Nominal	
	Index	SE	Index	SE
2002	235.38	28.10	184.26	23.94
2003	341.03	35.44	460.34	59.60
2004	301.81	23.29	418.47	50.54
2005	608.25	50.05	582.52	63.55
2006	244.91	20.11	341.86	39.46
2007	361.93	30.77	464.64	70.39
2008	390.04	27.58	450.77	51.68
2009	253.64	19.68	272.59	33.06
2010	342.06	25.16	350.95	39.90
2011	304.90	23.90	364.64	38.72
2012	178.94	14.78	148.92	15.58
2013	273.30	23.52	186.07	15.27
2014	206.75	17.16	152.63	16.18
2015	127.90	11.25	77.68	7.89
2016	171.35	15.62	82.15	8.10
2017	224.71	20.12	144.90	13.75
2018	331.29	27.54	254.43	26.14

Table 13. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices (eels per day) for fishway surveys in the Chambly Dam (St. Lawrence Basin). SE represents the standard error of the mean.

Year	ZINB		Nominal	
	Index	SE	Index	SE
2004	8.81	1.39	9.83	2.60
2005	12.02	1.67	20.87	5.44
2006	4.47	0.82	4.35	0.70
2007	9.04	1.28	12.76	3.95
2008	20.51	2.85	25.56	7.19
2009	6.24	1.07	9.00	2.75
2010	59.14	8.41	55.40	10.13
2011	8.62	1.28	9.96	2.17
2012	11.28	1.79	6.00	0.72
2013	11.34	1.71	13.65	2.92
2014	14.70	2.08	10.12	1.32
2015	26.24	3.59	18.37	2.13
2016	62.71	9.61	52.49	8.55
2017	1.62	0.30	1.77	0.27
2018	14.37	2.06	14.57	2.60

Table 14. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices (eels per tidal cycle) (May to November) at Saint Nicolas (St. Lawrence Basin). SE represents the standard error of the mean and blank cells indicate missing data.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1975	1.28	0.13	1.08	0.14
1976	1.89	0.19	1.35	0.10
1977	1.55	0.15	1.41	0.15
1978	1.78	0.16	1.79	0.23
1979	1.36	0.14	1.22	0.11
1980	0.92	0.10	0.94	0.09
1981	1.17	0.13	0.98	0.09
1982	1.00	0.10	0.91	0.08
1983	1.15	0.12	1.09	0.13
1984	1.19	0.12	0.95	0.09
1985	1.14	0.11	1.00	0.08
1986	1.12	0.12	0.96	0.10
1987	0.83	0.09	0.76	0.08
1988	0.90	0.10	0.85	0.10
1989	0.84	0.10	0.64	0.05
1990	0.92	0.10	0.77	0.09
1991	0.67	0.07	0.67	0.07
1992	0.89	0.10	0.81	0.07
1993	0.88	0.10	0.81	0.10
1994	0.99	0.10	0.92	0.10
1995	0.76	0.08	0.77	0.10
1996	0.82	0.09	0.71	0.07
1997	0.72	0.08	0.69	0.08
1998	0.97	0.10	0.91	0.10
1999	1.32	0.13	1.37	0.29
2000	1.01	0.11	0.92	0.11
2001	1.30	0.13	1.30	0.25
2002	1.09	0.12	1.06	0.16
2003	1.15	0.12	1.04	0.16
2004	0.91	0.10	0.87	0.12
2005	0.75	0.08	0.80	0.19
2006	0.70	0.08	0.76	0.12
2007	0.54	0.06	0.49	0.08
2008	0.80	0.09	0.75	0.11
2009	0.56	0.07	0.55	0.07
2010	0.65	0.08	0.73	0.11
2011	0.58	0.07	0.51	0.07
2012	0.58	0.07	0.63	0.09
2013	0.57	0.06	0.61	0.08
2014	0.57	0.06	0.60	0.08
2015	-	-	-	-
2016	-	-	-	-
2017	0.45	0.06	0.47	0.08
2018	0.87	0.17	1.39	0.09

Table 15. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices (eels per tidal cycle) for silver eels (October to November) at Saint Nicolas (St. Lawrence Basin). SE represents the standard error of the mean and blank cells indicate missing data.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1975	1.95	0.27	2.53	0.14
1976	1.67	0.26	1.79	0.10
1977	2.77	0.38	2.76	0.15
1978	3.72	0.50	4.15	0.23
1979	2.29	0.33	2.05	0.11
1980	1.51	0.23	1.62	0.09
1981	1.44	0.21	1.69	0.09
1982	1.70	0.24	1.52	0.08
1983	2.00	0.29	2.36	0.13
1984	1.31	0.19	1.56	0.09
1985	1.69	0.24	1.47	0.08
1986	1.44	0.21	1.89	0.10
1987	1.36	0.20	1.39	0.08
1988	1.82	0.27	1.89	0.10
1989	0.89	0.16	0.93	0.05
1990	1.42	0.21	1.57	0.09
1991	1.40	0.21	1.33	0.07
1992	1.46	0.22	1.29	0.07
1993	1.53	0.23	1.87	0.10
1994	1.64	0.23	1.86	0.10
1995	1.75	0.25	1.89	0.10
1996	1.07	0.17	1.29	0.07
1997	1.13	0.18	1.43	0.08
1998	1.73	0.24	1.78	0.10
1999	2.62	0.37	5.26	0.29
2000	1.54	0.22	2.01	0.11
2001	3.38	0.48	4.40	0.25
2002	2.19	0.33	2.87	0.16
2003	2.24	0.32	2.88	0.16
2004	1.81	0.26	2.07	0.12
2005	1.59	0.24	3.32	0.19
2006	2.01	0.29	2.05	0.12
2007	1.13	0.17	1.44	0.08
2008	1.27	0.20	1.96	0.11
2009	1.30	0.20	1.32	0.07
2010	1.45	0.22	1.63	0.11
2011	0.85	0.14	1.23	0.07
2012	1.41	0.21	1.53	0.09
2013	1.32	0.20	1.31	0.08
2014	1.23	0.18	1.39	0.08
2015	-	-	-	-
2016	-	-	-	-
2017	0.75	0.14	1.06	0.07
2018	0.87	0.17	1.39	0.09

Table 16. Model selection for the standardized abundance indices for Scotia-Fundy using zero-inflated (ZINB) and negative binomial (NB) GLMMs. Delta corrected Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error *(*rmse*), r^2 marginal (r^2 marg), r^2 conditional (r^2 cond), variance statistical significance of the variables tested *p < 0.05, **p=0.01, ***p < 0.01.*

a) Nahwaak

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse	r^2 cond	r^2 marg
Year*** + Temp** + Site + offset (Area)	~ Month**	0	ZINB	0.95	0.03	8.62	0.42	0.34
Year*** + Month + Temp* + Site + offset (Area)	~ Month**	5.0	ZINB	0.64	0.05	8.64	0.44	0.35
Year*** + Month + Flow + Temp* + Site + offset (Area)	~ Month** + Temp	11.3	ZINB	0.95	0.08	8.7	0.45	0.35
Year*** + Month + offset (Area)	~ Year + Month*	12.1	ZINB	0.61	0.87	8.81	NA	NA
Year*** + Month* + Temp* + Site + offset (Area)	~ Temp	13.2	ZINB	0.62	0.06	8.81	0.46	0.36
Year + Month + Temp + Site + offset (Area)	~ 0	80.9	NB	0.34	<0.01	8.48	0.51	0.45
Year + Month + Flow + Temp + Site + offset (Area)	~ 0	83.1	NB	0.42	<0.01	8.49	0.51	0.45
Year + Month + Site + offset (Area)	~ 0	83.1	NB	0.69	<0.01	8.5	0.50	0.44
Year + offset (Area)	~ 0	89.3	NB	0.10	0.01	8.86	NA	NA
Year + Month + offset (Area)	~ 0	90.3	NB	0.20	<0.01	8.84	NA	NA

b) LaHave

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse	r^2 cond	r^2 marg
Year*** + Month* + Flow + Site + offset (Area)	~ Flow**	0	ZINB	0.23	0.01	12.38	0.51	0.31
Year*** + Month* + Flow + Temp + Site + offset (Area)	~ Flow** + Temp	3.2	ZINB	0.43	0.05	12.31	0.47	0.29
Year*** + Flow* + Site + offset (Area)	~ Flow** + Temp	4.4	ZINB	0.08	<0.01	10.72	0.48	0.28
Year*** + Month* + Flow + Temp + Site + offset (Area)	~ 1	10.8	ZINB	0.61	0.06	13.31	0.52	0.32
Year*** + Month + offset (Area)	~ 0	41.4	NB	0.83	<0.01	9.71	0.64	0.38
Year*** + Month + Flow + Temp + Site + offset (Area)	~ 0	41.4	NB	0.49	<0.01	9.71	0.65	0.39
Year*** + Month + Temp + Site + offset (Area)	~ 0	62.1	NB	0.71	<0.01	9.72	0.65	0.38
Year*** + Month** + Site + offset (Area)	~ 0	74.7	NB	0.50	0.10	12.04	NA	NA
Year*** + offset (Area)	~ 0	79.1	NB	0.79	0.07	12.30	NA	NA

c) St. Marys

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse	r^2 cond	r^2 marg
~ Year*** + Flow + Site + offset (Area)	~ Flow + Temperature	0	ZINB	0.07	0.14	18.02	0.57	0.42
~ Year*** + Flow + Temperature + Site + offset (Area)	~ Flow + Temp	0.7	ZINB	0.2	0.14	18.07	0.58	0.41
~ Year*** + Month + Flow + Site + offset (Area)	~ Flow	2.9	ZINB	0.31	0.08	17.04	0.58	0.42
~ Year*** + Month + Flow + Temperature + Site + offset (Area)	~ Flow + Temp	4.9	ZINB	0.16	0.06	16.91	0.59	0.42
~ Year*** + Month + Site + offset (Area)	~ 0	19.2	NB	0.28	0.03	16.89	0.72	0.52
~ Year*** + Month + Temp + Site + offset (Area)	~ 0	20.7	NB	0.24	0.06	16.70	0.72	0.51
~ Year*** + Flow + Site + offset (Area)	~ Temp	21.8	ZINB	0.24	0.07	17.21	0.55	0.40
~ Year + Month + Flow + Temp + offset (Area)	~ 0	23.0	NB	0.12	0.02	16.40	0.72	0.51

d) All Rivers

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse
~ Year*** + Month + River*** + Flow*** + Temperature + offset (Area)	~ Year* + Month + Flow** + Temperature	0	ZINB	0.19	0.74	17.72
~ Year*** + Month + River*** + Flow** + Temperature + offset (Area)	~ Year* + Month*	6.5	ZINB	0.16	0.83	17.79
~ Year*** + Month + River*** + Flow*** + offset (Area)	~ Flow***	7.8	ZINB	0.07	0.63	17.45
~ Year*** + Month + River*** + Flow** + offset (Area)	~ Month + Flow***	8.2	ZINB	0.21	<0.01	17.54
~ Year*** + Month + River*** + Flow*** + Temperature + offset (Area)	~ Flow***	8.9	ZINB	0.16	0.56	17.45
~ Year*** + Month + River*** + Flow* + offset (Area)	~ 0	62.6	NB	0.21	0.18	18.14
~ Year*** + Month + River*** + Flow* + Temperature + offset (Area)	~ 0	64.1	NB	0.03	0.18	18.12
~ Year*** + Month + River*** + offset (Area)	~ 0	66.5	NB	0.02	0.17	17.92
~ Year*** + Month + River*** + Temperature + offset (Area)	~ 0	68.0	NB	0.12	0.16	17.91
~ Year*** + River*** + offset (Area)	~ 0	68.7	NB	0.08	0.09	17.54

Table 17. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels 100m^{-2}) in the Nashwaak River (Scotia-Fundy). SE represents the standard error of the mean.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1987	4.0	2.1	4.68	0.00
1988	1.7	0.5	3.36	1.79
1989	3.2	0.7	3.62	0.41
1990	3.1	0.8	3.16	0.67
1991	2.2	0.5	2.35	0.52
1992	0.7	0.2	0.91	0.32
1993	1.9	0.4	1.47	0.44
1994	1.1	0.3	0.46	0.21
1995	1.0	0.3	0.62	0.32
1996	1.3	0.3	1.39	0.22
1997	1.0	0.2	1.04	0.23
1998	1.3	0.3	1.22	0.26
1999	0.9	0.2	0.70	0.19
2000	1.0	0.2	1.26	0.27
2001	1.4	0.2	1.72	0.29
2002	1.3	0.3	1.36	0.35
2003	0.6	0.1	0.54	0.14
2004	1.6	0.3	2.05	0.41
2005	1.2	0.2	1.47	0.24
2006	0.8	0.1	0.85	0.15
2007	1.3	0.2	1.43	0.19
2008	1.1	0.2	1.27	0.28
2009	1.2	0.3	1.09	0.25
2010	0.8	0.2	1.08	0.30
2011	0.6	0.1	0.62	0.11
2012	1.5	0.3	1.73	0.34
2013	0.3	0.1	0.17	0.06
2014	0.7	0.1	0.75	0.06
2015	1.3	0.2	1.38	0.24
2016	1.7	0.3	1.80	0.41
2017	1.1	0.2	1.24	0.23
2018	1.2	0.3	1.41	0.25

Table 18. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels 100m^{-2}) in the LaHave River (Scotia-Fundy). SE represents the standard error of the mean.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1995	1.05	0.44	1.42	0.44
1997	0.75	0.27	1.16	0.38
1998	0.00	0.00	0.00	0.00
1999	1.04	0.40	0.69	0.28
2000	0.29	0.12	0.27	0.15
2001	2.12	1.09	0.77	0.34
2002	0.71	0.27	0.63	0.20
2003	0.34	0.12	0.36	0.10
2004	0.13	0.06	0.08	0.05
2005	0.14	0.05	0.21	0.08
2006	0.29	0.10	0.39	0.18
2007	0.01	0.01	0.01	0.01
2008	0.10	0.05	0.12	0.03
2009	0.24	0.08	0.27	0.11
2010	0.69	0.23	0.86	0.36
2011	0.38	0.14	0.39	0.15
2012	0.29	0.13	0.41	0.18
2013	0.41	0.15	0.51	0.32
2014	0.44	0.16	0.48	0.16
2015	0.62	0.21	0.71	0.37
2016	0.76	0.38	1.31	0.35
2017	0.41	0.14	0.54	0.26

Table 19. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels 100m^{-2}) in the St. Marys River (Scotia-Fundy). SE represents the standard error of the mean.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1995	6.76	1.59	10.07	3.14
1996	3.64	0.81	3.13	0.72
1997	5.06	1.08	5.34	0.95
1998	8.36	1.81	8.59	1.22
1999	4.97	1.07	5.73	1.23
2000	1.54	0.37	1.60	0.26
2001	1.86	0.40	1.95	0.51
2002	2.01	0.43	1.84	0.34
2003	1.19	0.26	1.26	0.26
2004	0.38	0.09	0.43	0.09
2005	1.34	0.30	1.32	0.23
2006	0.94	0.22	1.02	0.21
2007	1.68	0.37	1.89	0.50
2008	0.80	0.20	0.73	0.15
2009	1.05	0.27	1.03	0.15
2010	1.52	0.35	1.59	0.30
2011	1.30	0.32	1.34	0.29
2012	0.83	0.22	1.00	0.48
2013	1.25	0.32	1.36	0.35
2014	1.30	0.34	1.25	0.21
2015	1.37	0.35	1.66	0.53
2016	1.72	0.43	1.80	0.52
2017	1.92	0.46	1.89	0.37

Table 20. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels 100m^{-2}) in Scotia-Fundy rivers (Nashwaak, LaHave, and St Marys rivers). SE represents the standard error of the mean.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1995	2.66	0.39	3.61	1.01
1996	2.27	0.48	1.57	0.52
1997	2.23	0.36	2.43	0.53
1998	3.81	0.81	4.30	1.05
1999	1.86	0.38	2.11	0.57
2000	0.84	0.18	0.55	0.14
2001	1.49	0.29	0.81	0.21
2002	1.22	0.25	0.88	0.18
2003	0.69	0.14	0.52	0.12
2004	1.01	0.18	0.13	0.03
2005	0.99	0.15	0.37	0.09
2006	0.79	0.12	0.33	0.09
2007	1.24	0.21	0.57	0.19
2008	0.81	0.14	0.27	0.07
2009	0.92	0.16	0.54	0.11
2010	1.29	0.21	0.89	0.20
2011	0.85	0.15	0.60	0.14
2012	1.06	0.20	0.43	0.16
2013	0.72	0.15	0.49	0.14
2014	0.84	0.13	0.37	0.09
2015	1.39	0.24	0.85	0.26
2016	1.61	0.33	1.01	0.26
2017	`1.21	0.21	0.90	0.21

Table 21. Model selection for the standardized abundance indices for elvers in Scotia-Fundy using negative binomial (NB) GLMs. Delta corrected Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error (rmse*), variance statistical significance of the variables tested *p < 0.05, **p=0.01, ***p < 0.01.*

East River Chester						
Conditional model	**Zero-Inflation model**	**ΔAICc**	**Distribution**	**KS test**	**Disp p-value**	**rmse**
~ Year*** + Month*** + Tide***	~ 0	0	NB	0.05	0.82	11.62
~ Year*** + Month*** + Tide*** + Temperature	~ 0	1.9	NB	<0.01	0.74	11.70
~ Year*** + Month***	~ 0	12.9	NB	0.03	0.99	10.91
~ Year*** + Month*** + Water Level + Temperature	~ 0	14.1	NB	0.10	0.99	10.87
~ Year*** + Month*** + Temperature	~ 0	14.5	NB	0.03	0.99	10.91

Table 22. Abundance indices calculated using a negative binomial model (NB) and nominal abundance indices for elver trap surveys (per kg) in East River Chester (Scotia-Fundy). SE represents the standard error of the mean.

Year	NB		Nominal	
	Index	SE	Index	SE
1996	2.89	0.63	2.34	0.87
1997	3.54	0.84	3.56	2.90
1998	0.43	0.11	0.43	0.26
1999	1.07	0.25	1.16	0.44
2000	1.83	0.39	1.99	0.88
2001	1.56	0.39	1.77	1.46
2002	5.97	1.69	7.01	5.54
2003	-	-	-	-
2004	-	-	-	-
2005	-	-	-	-
2006	-	-	-	-
2007	-	-	-	-
2008	4.92	1.19	4.26	2.25
2009	1.22	0.27	1.50	1.18
2010	0.72	0.17	0.67	0.25
2011	4.35	1.07	5.18	1.89
2012	3.34	0.71	3.21	0.97
2013	3.77	0.78	3.85	1.48
2014	4.29	0.93	4.98	1.89
2015	1.72	0.43	2.31	1.22
2016	23.84	6.38	14.06	4.57
2017	3.50	0.80	2.70	0.14
2018	28.69	7.04	14.91	0.21

Table 23. Model selection for the standardized abundance indices for the Southern Gulf of St. Lawrence for zero-inflated (ZINB) and negative binomial (NB) GLMMs. Delta corrected Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error (rmse)*, r^2 marginal (r^2 marg), r^2 conditional (r^2 cond), variance statistical significance of the variables tested *p < 0.05, **p=0.01, ***p < 0.01.*

a) Restigouche

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS p-value	Disp p-value	rmse	r^2 cond	r^2 marg
~ Year*** + Month + Flow + Temperature + Site + offset (Area)	~ Month** + Temperature + Site	0	ZINB	0.84	<0.01	4.49	0.46	0.37
~ Year*** + Month + Temperature + Site + offset (Area)	~ Temperature* + Site	10.1	ZINB	0.277	<0.01	3.47	0.4	0.33
~ Year*** + Month + Flow + Temperature + Site + offset (Area)	~ Flow + Temperature* + Site	13.2	ZINB	0.36	<0.01	3.47	0.4	0.32
~ Year** + Temperature + Site + offset (Area)	~ Month + Temperature	69.7	ZINB	0.43	<0.01	4.48	0.75	0.01
~ Year** + Month** + Temperature + Site + offset (Area)	~ Month + Temperature	70.5	ZINB	0.08	<0.01	4.96	0.74	0.02
~ Year** + Month + Temperature + Site + offset (Area)	~ 0	97.2	NB	<0.01	<0.01	5.58	0.87	0.03
~ Year*** + Month + Site + offset (Area)	~ 0	97.3	NB	<0.01	<0.01	5.38	0.87	0.03
~ Year*** + Month* + Flow*** + Temperature** + Site + offset (Area)	~ 0	98.8	NB	<0.01	<0.01	2.51	0.86	0.02
~ Year*** + Month + Flow + Site + offset (Area)	~ 0	98.8	NB	<0.01	<0.01	5.4	0.87	0.03

b) Miramichi

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse	r^2 cond	r^2 marg
~ Year*** + Flow* + Site + offset (Area)	~ Temperature*** + Site	0	ZINB	0.03	0.04	6.7	0.45	0.16
~ Year*** + Flow* + Temperature + Site + offset (Area)	~ Flow + Temperature*** + Site	0.5	ZINB	0.08	0.32	6.7	0.45	0.16
~ Year*** + Month + Flow* + Temperature* + Site + offset (Area)	~ Flow + Temperature*** + Site	3.1	ZINB	<0.01	<0.01	6.64	0.46	0.16
~ Year*** + Month + Flow* + Site + offset (Area)	~ Temperature*** + Site	5.1	ZINB	0.02	0.02	6.69	0.46	0.16
~ Year*** + Month + Flow* + Site + offset (Area)	~ Flow + Temperature*** + Site	6.5	ZINB	0.51	0.03	6.7	0.45	0.16
~ Year*** + Month*** + Flow*** + Site + offset (Area)	~ 0	163.3	NB	0.26	<0.01	7.24	0.68	0.15
~ Year*** + Month*** + Flow*** + Temperature + Site + offset (Area)	~ 0	187.7	NB	0.11	<0.01	7.26	0.67	0.15
~ Year*** + Month*** + Site + offset (Area)	~ 0	194.8	NB	0.43	<0.01	7.77	0.68	0.13
~ Year*** + Month** + Temperature + Site + offset (Area)	~ 0	196.5	NB	0.2	<0.01	7.83	0.68	0.13
~ Year*** + Site + offset (Area)	~ 0	205.5	NB	0.77	<0.01	7.07	0.67	0.12

c) All Rivers

Conditional model	Zero-Inflation model	ΔAICc	Distribution	KS test	Disp p-value	rmse
~ Year*** + Month* + River + Temperature + Flow*** + offset (Area)	~ Year*** + Month + Temperature** + Flow***	0	ZINB	0.2	0.89	7.37
~ Year*** + Month** + River + offset (Area)	~ Year*** + Month + River***	58.3	ZINB	0.82	0.93	7.39
~ Year*** + Month* + River + offset (Area)	~ Year***	128.9	ZINB	0.47	0.68	7.39
~ Year*** + Month* + River + Temperature + Flow*** + offset (Area)	~ Month	652.8	ZINB	0.27	0.02	4.47
~ Year*** + Month* + River + Temperature* + offset (Area)	~ Temperature** + Flow***	680.1	ZINB	0.23	0.75	7.36
~ Year*** + Month* + offset (Area)	~ 0	771.2	NB	0.11	<0.01	7.43
~ Year*** + Month + River* + Flow*** + offset (Area)	~ 0	801	NB	0.78	<0.01	7.42
~ Year*** + Month* + River + Temperature + offset (Area)	~ 0	802.7	NB	0.43	<0.01	7.42
~ Year*** + Month* + River* + offset (Area)	~ 0	804.6	NB	0.2	<0.01	7.42

Table 24. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels 100m^{-2}) in the Restigouche River (Southern Gulf). SE represents the standard error of the mean and blank cells indicate missing data.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1972	0.26	0.12	0.43	0.15
1973	0.25	0.10	0.50	0.11
1974	0.21	0.09	0.35	0.12
1975	0.51	0.21	1.01	0.27
1976	0.19	0.09	0.23	0.10
1977	0.23	0.10	0.37	0.12
1978	0.23	0.11	0.28	0.08
1979	0.12	0.07	0.10	0.05
1980	0.35	0.18	0.48	0.26
1981	0.11	0.06	0.09	0.05
1982	0.07	0.04	0.09	0.07
1983	0.29	0.14	0.51	0.23
1984	-	-	-	-
1985	0.17	0.08	0.32	0.09
1986	0.31	0.14	0.48	0.19
1987	0.21	0.11	0.29	0.18
1988	0.46	0.22	0.76	0.45
1989	0.34	0.17	0.60	0.47
1990	0.29	0.18	0.36	0.22
1991	0.16	0.13	0.21	0.21
1992	0.15	0.22	0.06	0.06
1993	0.00	0.00	0.00	0.00
1994	0.29	0.19	0.31	0.21
1995	0.00	0.00	0.00	0.00
1996	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00
1998	1.22	0.98	0.22	0.22
1999	0.69	0.45	0.43	0.29
2000	0.60	0.34	0.46	0.21
2001	1.41	0.85	2.05	0.99
2002	1.87	1.13	2.45	1.14
2003	0.60	0.36	0.40	0.19
2004	1.36	0.87	0.86	0.39
2005	0.97	0.59	1.08	0.55
2006	1.43	0.78	1.41	0.67
2007	0.20	0.16	0.67	0.34
2008	0.26	0.23	0.43	0.21
2009	0.41	0.36	0.39	0.27
2010	0.63	0.46	0.69	0.42
2011	0.17	0.20	0.09	0.09
2012	0.72	0.46	0.56	0.28
2013	0.96	0.58	1.06	0.49
2014	0.30	0.26	0.49	0.34
2015	0.34	0.28	0.39	0.22
2016	0.70	0.41	0.94	0.39
2017	0.78	0.48	1.69	0.73
2018	0.36	0.24	0.86	0.56

Table 25. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels 100m^{-2}) in the Miramichi River (Southern Gulf). SE represents the standard error of the mean.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1952	1.11	0.59	0.56	0.25
1953	1.13	0.48	1.13	0.26
1954	0.21	0.12	0.31	0.10
1955	0.40	0.19	0.57	0.15
1956	0.26	0.13	0.40	0.16
1957	0.23	0.13	0.25	0.10
1958	0.23	0.15	0.28	0.20
1959	1.28	0.60	2.01	0.70
1960	0.49	0.29	0.87	0.45
1961	0.25	0.17	0.37	0.17
1962	0.14	0.12	0.14	0.07
1963	0.33	0.18	0.44	0.27
1964	0.69	0.29	1.17	0.52
1965	0.85	0.42	0.87	0.32
1966	0.77	0.33	1.07	0.48
1967	0.85	0.35	1.02	0.31
1968	0.85	0.37	1.42	0.64
1969	0.50	0.22	0.62	0.20
1970	0.32	0.15	0.31	0.08
1971	1.20	0.44	1.90	0.74
197.2	1.14	0.41	1.46	0.44
1973	0.98	0.36	1.25	0.44
1974	0.90	0.32	1.57	0.70
1975	1.15	0.41	1.23	0.27
1976	0.75	0.29	1.06	0.25
1977	0.92	0.32	1.24	0.43
1978	0.69	0.25	0.65	0.14
1979	0.16	0.08	0.16	0.04
1980	0.13	0.07	0.15	0.04
1981	0.32	0.14	0.37	0.08
1982	0.70	0.27	0.89	0.36
1983	0.79	0.31	0.94	0.32
1984	0.61	0.22	0.47	0.11

Year	ZINB		Nominal	
	Index	SE	Index	SE
1985	0.22	0.11	0.18	0.06
1986	0.21	0.12	0.15	0.06
1987	0.22	0.15	0.18	0.08
1988	0.26	0.16	0.27	0.14
1989	0.08	0.07	0.07	0.07
1990	0.27	0.19	0.25	0.14
1991	0.00	0.00	0.00	0.00
1992	0.12	0.11	0.16	0.12
1993	0.75	0.37	0.64	0.20
1994	0.14	0.11	0.21	0.09
1995	0.08	0.07	0.07	0.05
1996	0.92	0.73	0.67	0.54
1997	0.57	0.38	0.32	0.20
1998	0.61	0.39	0.51	0.19
1999	0.95	0.62	0.87	0.32
2000	0.92	0.58	0.59	0.21
2001	1.23	0.67	1.36	0.47
2002	0.73	0.45	0.57	0.32
2003	0.90	0.52	0.55	0.20
2004	0.67	0.39	0.79	0.43
2005	1.03	0.55	0.98	0.28
2006	0.57	0.31	0.68	0.25
2007	1.22	0.68	1.46	0.44
2008	0.56	0.36	0.43	0.19
2009	0.83	0.47	0.77	0.26
2010	0.61	0.37	0.75	0.34
2011	0.12	0.09	0.12	0.09
2012	1.04	0.57	1.25	0.52
2013	0.51	0.35	0.62	0.49
2014	0.43	0.27	0.23	0.10
2015	0.27	0.23	0.31	0.18
2016	0.25	0.19	0.13	0.09
2017	0.07	0.05	0.07	0.07
2018	0.91	0.71	0.65	0.25

Table 26. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for electrofishing surveys (eels 100m^{-2}) in New Brunswick rivers (Restigouche and Miramichi rivers, Southern Gulf of St. Lawrence). SE represents the standard error of the mean.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1972	1.20	0.26	1.24	0.35
1973	0.99	0.23	1.09	0.35
1974	0.81	0.18	1.30	0.55
1975	1.22	0.21	1.17	0.21
1976	0.80	0.19	0.83	0.19
1977	1.06	0.20	1.00	0.31
1978	0.56	0.11	0.54	0.10
1979	0.14	0.04	0.13	0.03
1980	0.32	0.09	0.31	0.13
1981	0.24	0.06	0.23	0.05
1982	0.52	0.16	0.6	0.23
1983	0.84	0.25	0.78	0.21
1984	0.48	0.12	0.47	0.11
1985	0.27	0.07	0.25	0.06
1986	0.30	0.10	0.31	0.10
1987	0.24	0.10	0.24	0.10
1988	0.56	0.22	0.52	0.24
1989	0.39	0.18	0.33	0.24
1990	0.29	0.15	0.30	0.13
1991	0.23	0.25	0.21	0.21
1992	0.10	0.07	0.12	0.08
1993	0.64	0.24	0.64	0.20
1994	0.20	0.08	0.22	0.08
1995	0.09	0.06	0.07	0.05
1996	0.96	0.77	0.67	0.54
1997	0.35	0.26	0.32	0.2
1998	0.53	0.23	0.4	0.15
1999	0.71	0.28	0.7	0.23
2000	0.67	0.23	0.53	0.15
2001	1.64	0.51	1.77	0.61
2002	1.50	0.56	1.64	0.67
2003	0.43	0.19	0.47	0.14
2004	0.91	0.32	0.82	0.29
2005	1.04	0.32	1.04	0.35
2006	0.94	0.34	1.09	0.39
2007	0.89	0.26	0.9	0.27
2008	0.51	0.25	0.43	0.15
2009	0.53	0.22	0.56	0.19
2010	0.68	0.37	0.71	0.28
2011	0.06	0.06	0.10	0.06
2012	0.86	0.31	0.82	0.26
2013	0.82	0.46	0.94	0.38
2014	0.41	0.18	0.39	0.21
2015	0.33	0.18	0.36	0.15
2016	0.73	0.32	0.62	0.24
2017	1.16	0.56	1.04	0.45
2018	0.68	0.25	1.08	0.53

Table 27. Model selection for the standardized abundance indices for the northern Gulf of St. Lawrence for zero-inflated (ZINB) and negative binomial (NB) GLMMs. Delta second-order Akaike Information Criterion (ΔAICc), Deviance (Dev), Kolmogorov-Smirnov test (KS), Dispersion test (Disp), root mean square error *(*rmse*), statistical significance of the variables tested *p < 0.05, **p=0.01, ***p < 0.01.*

Sud-Ouest						
Conditional model	**Zero-Inflation model**	**ΔAICc**	**Distribution**	**KS test**	**Disp p-value**	**rmse**
~ Year*** + Month*** + Flow* + Temperature***	~ Year* + Month + Flow + Temperature**	0	ZINB	0.13	0.8	75.37
~ Year*** + Month*** + Flow* + Temperature***	~ Flow + Temperature****	30	ZINB	0.02	0.66	61.67
~ Year*** + Month*** + Flow* + Temperature***	~ 0	41	NB	0.03	0.56	63.55
~ Year*** + Month*** + Temperature***	~ 0	42.8	NB	0.03	0.53	69.03
~ Year*** + Month*** + Temperature***	~ Temperature***	67.3	ZINB	0.14	0.66	63.24
~ Year*** + Flow + Temperature***	~ Temperature***	69.2	ZINB	0.29	0.54	62.72
~ Year*** + Flow + Temperature***	~ Flow + Temperature****	71.1	ZINB	0.07	0.59	64.77
~ Year*** + Month***	~ 0	234.3	NB	0.01	0.81	30.17
~ Year*** + Month*** + Flow***	~ 0	252.9	NB	0.15	0.82	29.85

Table 28. Abundance indices calculated using a zero-inflated negative binomial model (ZINB) and nominal abundance indices for trap surveys (per day) in the Sud-Ouest River (St. Lawrence Basin). SE represents the standard error of the mean.

Year	ZINB		Nominal	
	Index	SE	Index	SE
1999	9.4	2.8	6.0	0.9
2000	1.1	0.5	2.4	0.5
2001	2.9	1.1	4.4	0.6
2002	7.9	3.7	1.0	0.2
2003	9.3	2.7	8.2	2.1
2004	8.5	2.3	7.6	1.4
2005	13.9	3.0	35.1	10.4
2006	23.6	4.6	29.7	6.0
2007	2.6	0.6	2.8	0.5
2008	7.8	1.6	10.0	2.6
2009	2.1	0.4	2.3	0.7
2010	57.1	12.9	34.4	6.8
2011	9.2	2.0	11.2	2.6
2012	8.6	1.7	10.3	1.7
2013	3.1	0.8	4.9	1.7
2014	16.2	4.5	12.5	3.8
2015	16.0	3.7	14.1	3.4
2016	11.9	3.0	11.2	1.8

Table 29. Results of power analysis for American eel abundance indices. For each survey linear and exponential trends were tested over a ten-year period.

					Linear trend		Exponential trend	
Zones	**Survey**	**Years**	**n**	**Median CV**	**50%**	**-50%**	**50%**	**-50%**
St. Lawrence Basin	**Bay of Quinte**	1972-2017	67	0.52	0.12	0.17	0.12	0.19
	Saint Nicolas (May-Oct)	1975-2018	42	0.10	0.98	1.00	0.98	1.00
	Saint Nicolas (Sept-Oct)	1975-2018	42	0.15	0.83	0.93	0.77	0.93
	Beauharnois	2002-2018	17	0.08	1.00	1.00	1.00	1.00
	Chambly	2004-2018	14	0.15	0.75	0.92	0.75	0.93
Scotia-Fundy	**Nashwaak**	1987-2018	31	0.25	0.36	0.54	0.36	0.55
	LaHave	1995-2017	22	0.41	0.16	0.24	0.17	0.26
	St. Mary`s	1995-2017	23	0.23	0.41	0.60	0.41	0.62
	All rivers combined	1995-2018	23	0.22	0.60	0.81	0.60	0.81
Southern Gulf	**Miramichi**	1952-2018	67	0.52	0.12	0.17	0.12	0.19
	Restigouche	1972-2018	46	0.62	0.09	0.13	0.10	0.15
	All rivers combined	1972-2018	46	0.37	0.19	0.28	0.20	0.31
Northern Gulf	**Sud-Ouest River**	1999-2016	18	0.59	0.63	0.84	0.64	0.86

Table 30. Mann-Kendal test (MK) and modified Mann-Kendal test (MK corrected) results for American eel abundance indices. NS represents a non-significant trend.

				MK		MK corrected				
Zones	**Survey**	**Years**	**Stage**	**p-value**	**Z**	**p-value**	**Z**	**MK τ**	**Sen`s Slope**	**Trend**
St. Lawrence	**Moses-Saunders**	1975-2018	Yellow	**<0.01**	-5.47	**<0.01**	-4.53	-0.69	-2.87	-
Basin	**Bay of Quinte**	1972-2017	Yellow	**<0.01**	-6.74	**<0.01**	-4.48	-0.70	-0.06	-
	Saint Nicolas (May-Oct)	1975-2018	Yellow/Silver	**<0.01**	-5.63	**<0.01**	-4.31	-0.60	-0.19	-
	Saint Nicolas (Sept-Oct)	1975-2018	Silver	**0.01**	-2.73	**<0.01**	-2.73	-0.29	-0.02	-
	Beauharnois	2002-2018	Yellow	0.09	-1.69	0.09	-1.69	-0.31	-9.44	NS
	Chambly	2004-2018	Yellow	0.20	1.28	0.20	1.28	0.26	0.60	NS
Scotia-	**Nashwaak**	1987-2018	Yellow	**0.02**	-2.40	**0.02**	-2.40	-0.29	-0.03	-
Fundy	**LaHave**	1995-2017	Yellow	0.62	0.50	0.69	0.39	0.08	-0.007	NS
	St. Mary`s	1995-2017	Yellow	0.04	-2.09	0.20	-1.28	-0.32	-0.07	NS
	All rivers combined	1995-2017	Yellow	0.11	-1.61	0.24	-1.17	-0.24	-0.03	NS
	East River Chester	1996-2018	Elvers	**0.03**	2.12	**0.03**	2.12	0.37	12.9	+
Southern	**Miramichi**	1952-2018	Yellow	0.69	-0.40	0.58	-0.55	-0.03	-0.001	NS
Gulf	**Restigouche**	1972-2018	Yellow	**<0.01**	2.69	**0.01**	2.44	0.27	0.009	+
	All rivers combined	1972-2018	Yellow	0.79	0.26	0.86	0.18	-0.23	-0.002	NS
Northern Gulf	**Sud-Ouest**	1999-2016	Yellow	0.20	1.29	0.20	1.28	0.23	28.0	NS

Table 31. Results for ARIMA model for fishery-independent data. Number of years (n), Standard error (SE), Variance (σ^2), Akaike information criterion (AIC), root mean square error (RMSE)*, Mean Error (ME), Mean Absolute error (MAE), Mean Percent error (MPE), Mean Absolute Percentage Error (MAPE), Mean Standard error (MSE), Autocorrelation Function (ACF).*

Zone	Survey	Years	n	ar(1)	ar(2)	ar(3)	SE	theta	σ^2	Q 25%	P(<0.25) initial year	P(<0.25) year 2012	P(<0.25) terminal year
St. Lawrence Basin	**Bay of Quinte**	1972-2017	45	-0.47	0.24	-0.31	0.12	0.37	0.65	-4.68	**0**	0.23	**0.03**
	Saint Nicolas (May-Oct)	1975-2018	42	-0.42	0.01	-0.11	0.14	0.58	0.14	0.28	**0.02**	0.97	0.94
	Saint Nicolas (Sept-Oct)	1975-2018	42	-0.05	0.30	-0.20	0.13	0.99	0.04	-0.34	**0**	0.87	0.99
	Beauharnois	2002-2018	17	-0.46	0.04	0.24	0.29	0.65	0.13	5.45	0.24	0.28	0.66
	Chambly	2004-2018	15	-0.60	0.10	0.03	0.22	1.00	0.85	2.24	0.49	0.38	0.27
Scotia-Fundy	**Nashwaak**	1987-2018	31	-0.50	-0.07	0.13	0.14	0.69	0.20	-0.01	**<0.01**	0.59	0.40
	LaHave	1995-2017	22	-0.53	0.27	-0.34	0.34	1.00	0.57	0.70	0.15	0.47	0.57
	St. Mary`s	1995-2017	23	-0.27	-0.19	-0.08	0.19	0.38	0.25	0.13	**0**	0.42	0.14
	All rivers combined	1995-2017	23	-0.30	-0.37	0.48	0.43	0.47	0.09	0.02	**0**	0.62	0.11
South Gulf	**Miramichi**	1952-2018	67	-0.36	-0.14	0.05	0.77	0.37	0.67	-1.25	0.12	0.14	0.18
	Restigouche	1972-2018	46	-0.43	0.10	-0.17	0.39	0.36	1.02	-1.84	0.18	0.05	0.09
	All rivers combined	1972-2018	46	-0.44	-0.16	0.26	0.12	0.69	0.50	-0.90	0.06	0.12	0.09
North Gulf	**Sud-Ouest**	1999-2016	18	-0.54	0.22	-0.46	0.23	0.91	0.98	2.13	0.26	0.36	0.34

Table 31 (continued).

Zone	Survey	AIC	p Ljungbox	rmse	ME	MAE	MPE	MAPE	MASE	ACF
St. Lawrence Basin	**Bay of Quinte**	110.14	0.05	0.82	-0.18	0.61	73.29	119.96	0.96	-0.10
	Saint Nicolas (May-Oct)	-14.8	0.31	0.19	-0.04	0.15	27.90	279.18	0.86	-0.99
	Saint Nicolas (Sept-Oct)	21.91	0.90	0.30	-0.04	0.23	-0.64	84.53	0.84	0.00
	Beauharnois	17.33	0.70	0.35	-0.02	0.27	-0.68	4.86	0.71	-0.04
	Chambly	44.19	0.42	0.89	0.14	0.61	-23.04	44.59	0.53	-0.36
Scotia-Fundy	**Nashwaak**	42.45	0.79	0.48	-0.11	0.35	3046.18	3643.61	0.72	-0.13
	LaHave	75.34	0.58	1.20	0.16	1.04	121.32	313.6	0.69	-0.13
	St. Mary`s	38.68	0.16	0.38	-0.09	0.52	39.38	101.26	0.84	-0.02
	All rivers combined	20.08	0.87	0.32	-0.05	0.35	-216.	387.88	0.88	0.09
South Gulf	**Miramichi**	179.51	0.34	0.82	-0.01	0.61	-49.77	334.10	0.88	-0.03
	Restigouche	144.61	0.87	1.10	0.00	0.78	-98.24	244.17	0.88	-0.09
	All rivers combined	103.37	0.30	0.70	-0.03	0.52	-170.92	296.67	0.83	-0.01
North Gulf	**Sud-Ouest**	53.6	0.09	0.30	0.24	0.77	-132.56	169.28	0.72	-0.13

FIGURES

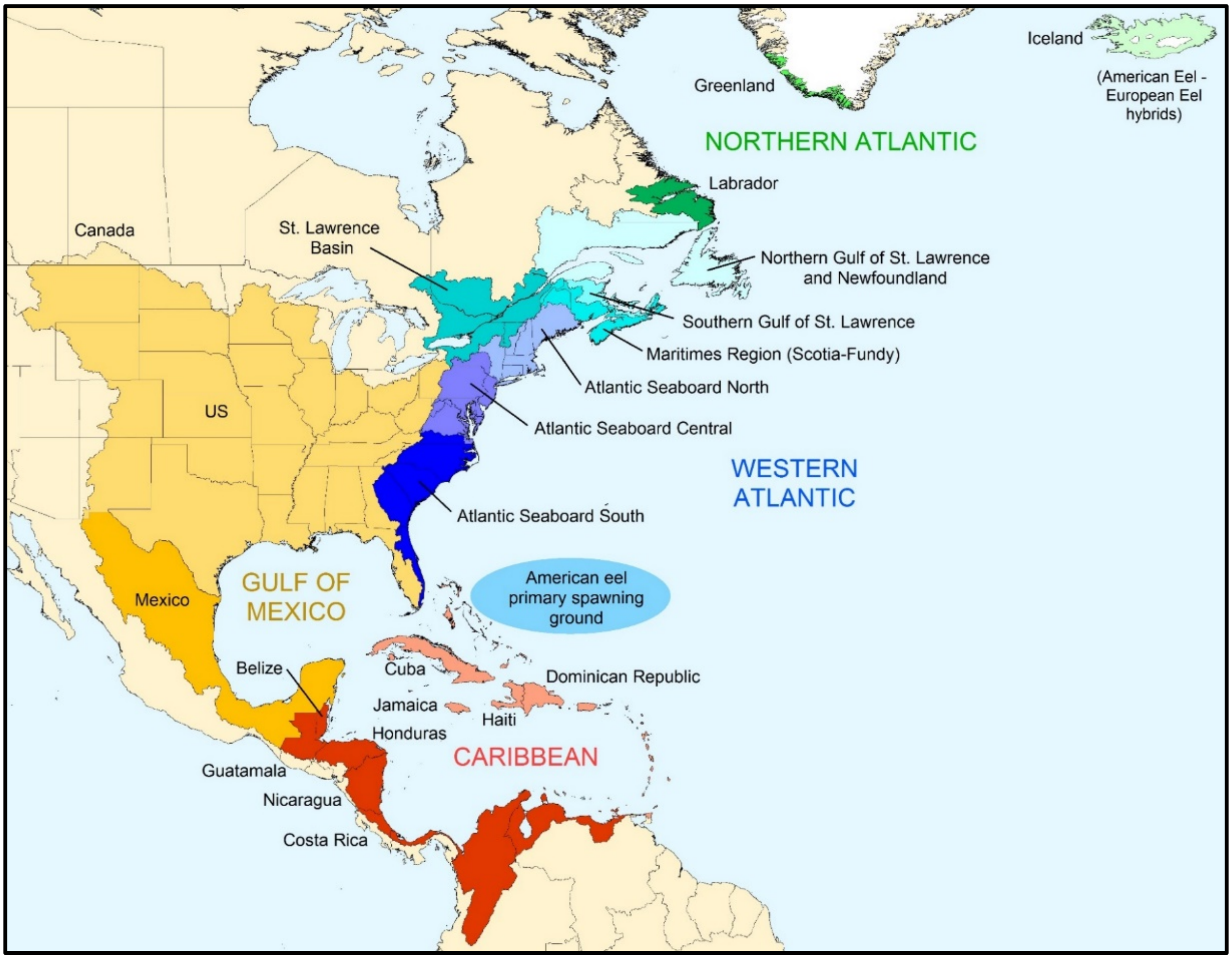


Figure 1. American eel Recovery Potential Assessment (RPA) Zones (from Cairns et al. 2014).

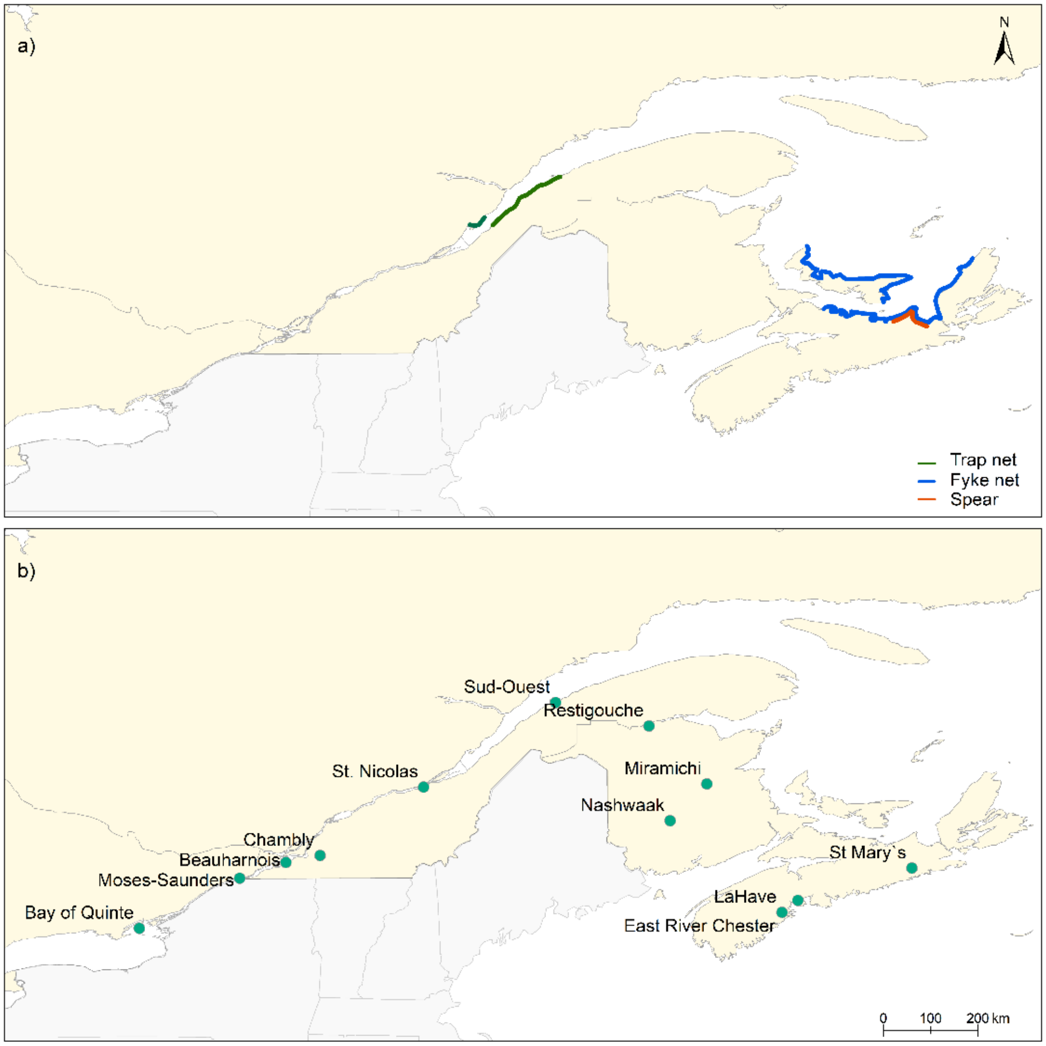


Figure 2. Fish surveys including American eel in Canada: a) fishery-dependent surveys and b) fishery-independent surveys.

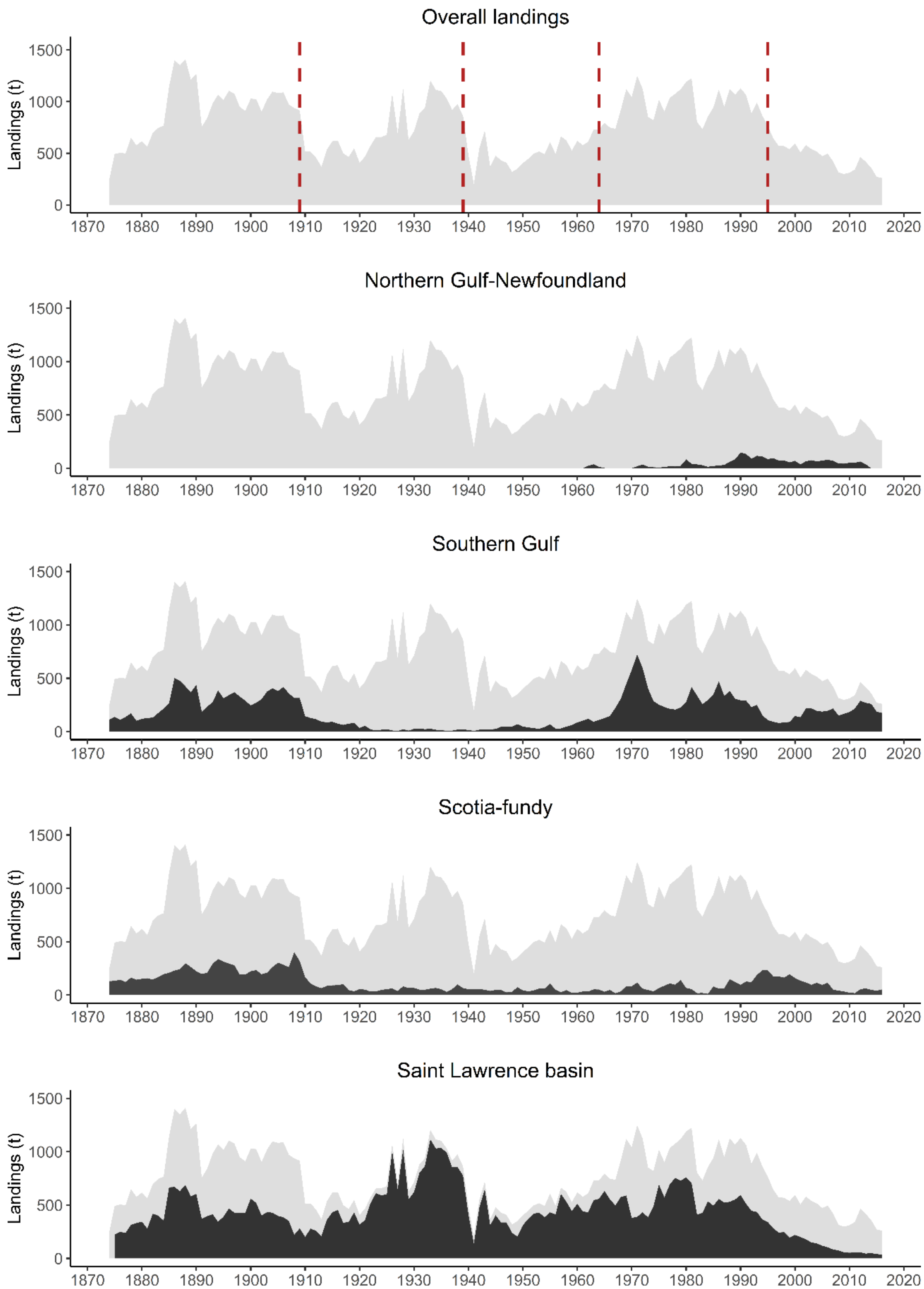


Figure 3. Reported American eel landings in Recovery Potential Assessment (RPA) zones of Canada. Grey represents overall Canadian landings and black each RPA zone. Red lines indicate periods of change in landings as detected by the breakpoint analysis.

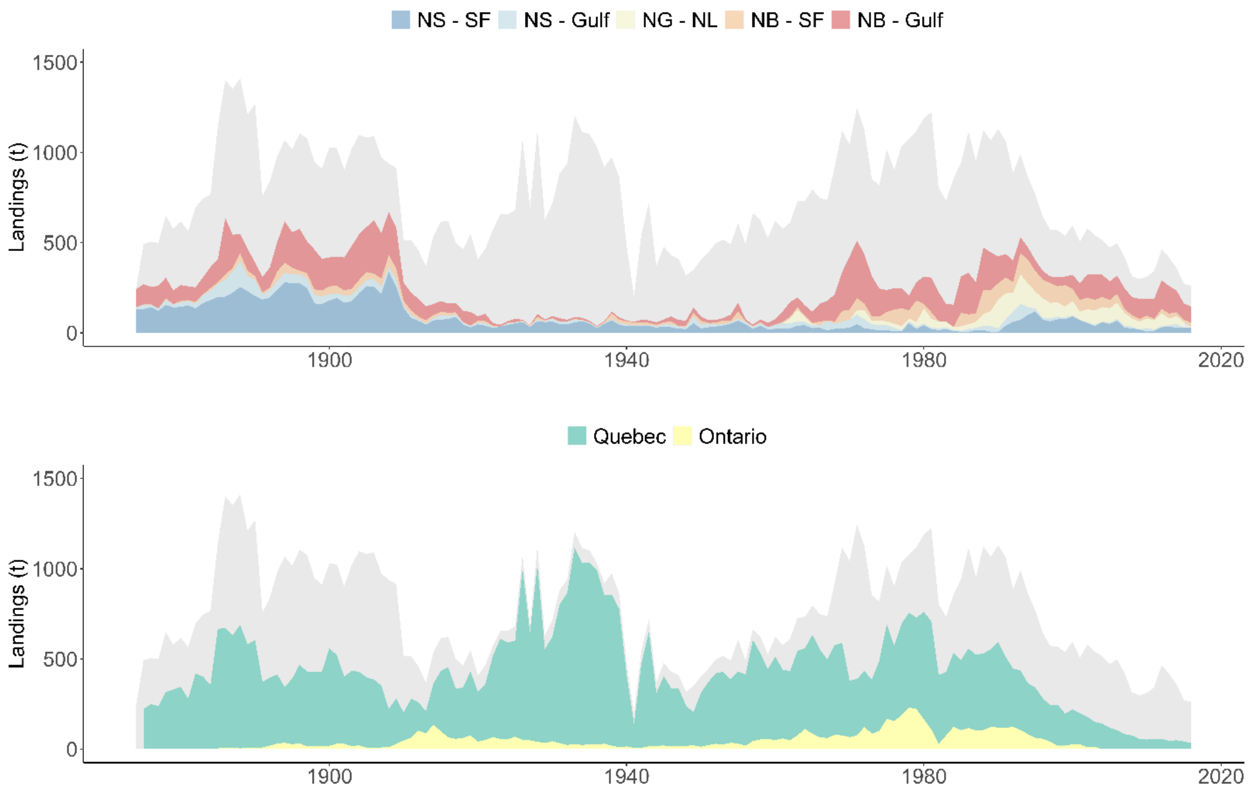


Figure 4. Reported American eel landings in coastal (upper panel) and freshwater (lower panel) habitat in Nova Scotia (NS) and New Brunswick (NB) in Scotia-Fundy (SF) and the southern Gulf of St. Lawrence (SG) management zones, and northern Gulf of St. Lawrence and Newfoundland (NG-NL). Quebec landings include silver eels caught in brackish and salt waters of the St. Lawrence Estuary, but these are included in the freshwater panel because they were reared in freshwater. Grey indicates the overall landings in Canada.

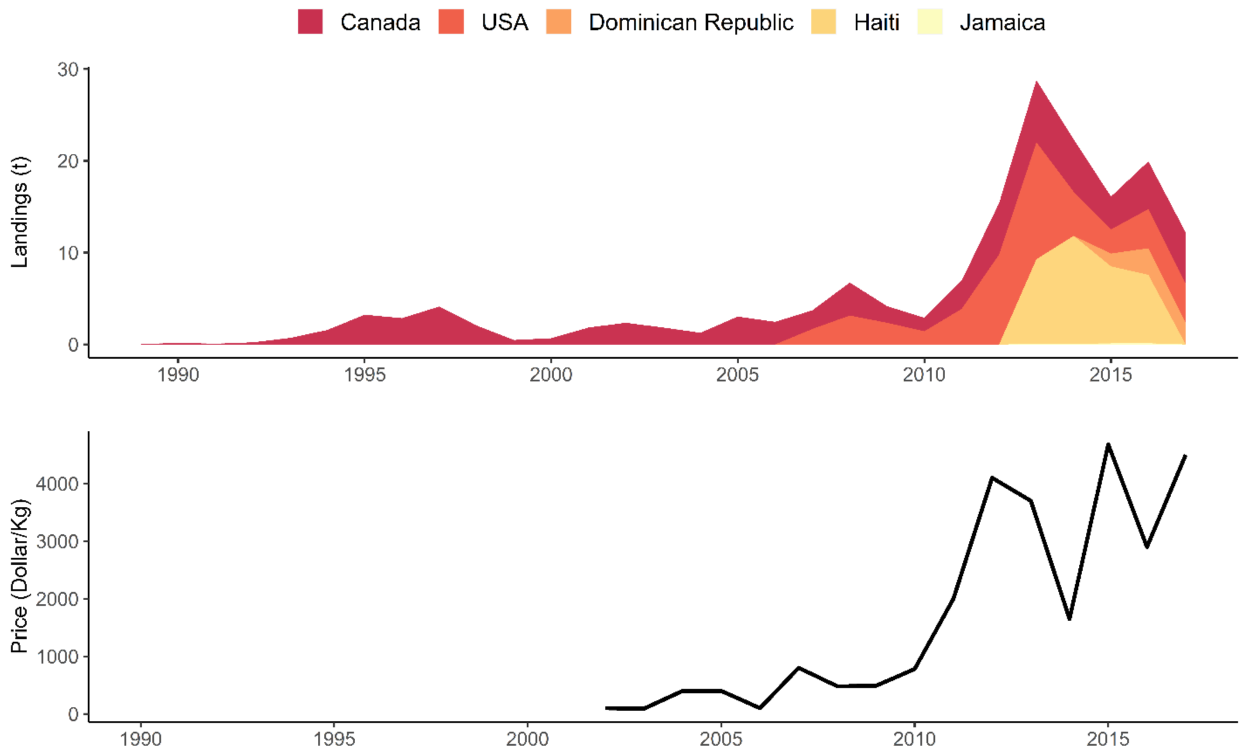


Figure 5. Reported American eel elver landings (top panel) and elver price per kg in Canada (lower panel).

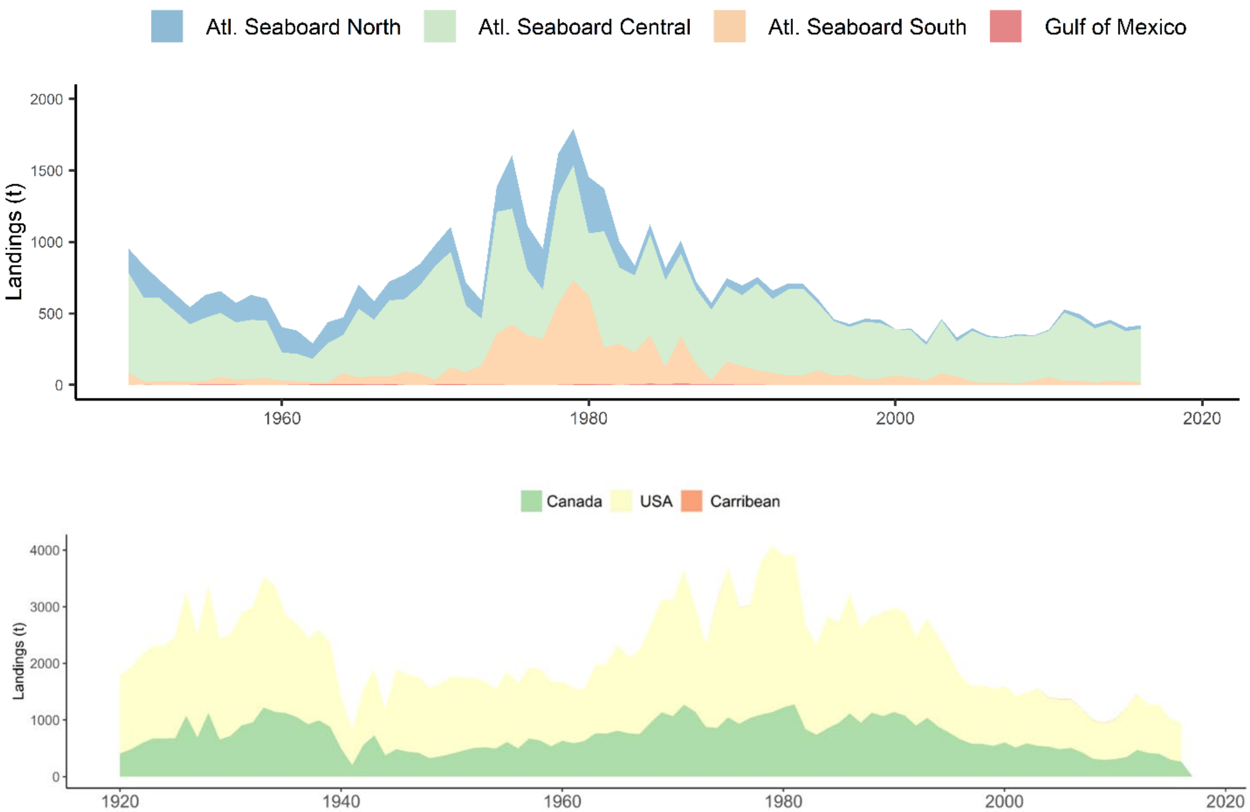


Figure 6. Reported American eel landings in the US (upper panel) and overall landings (lower panel).

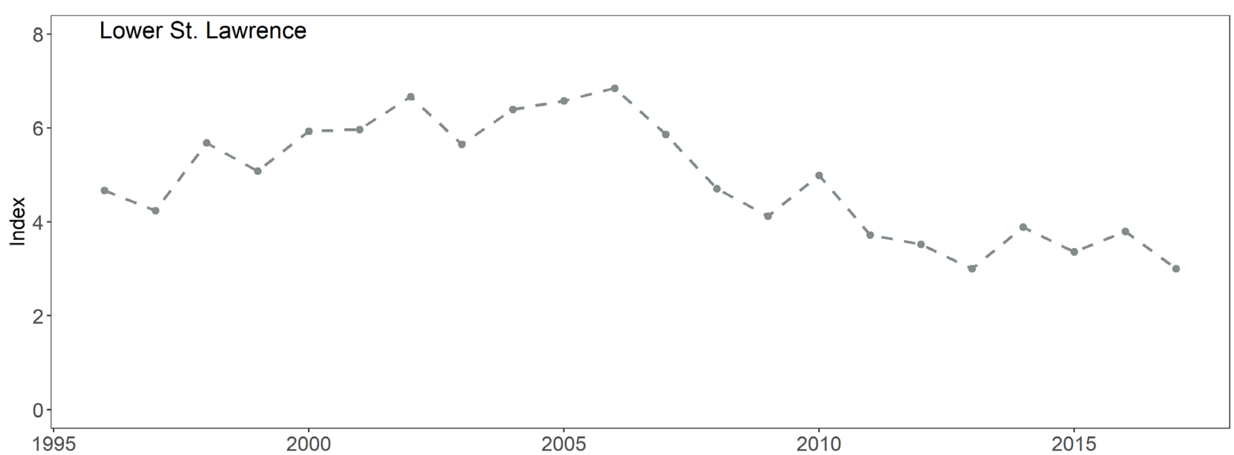
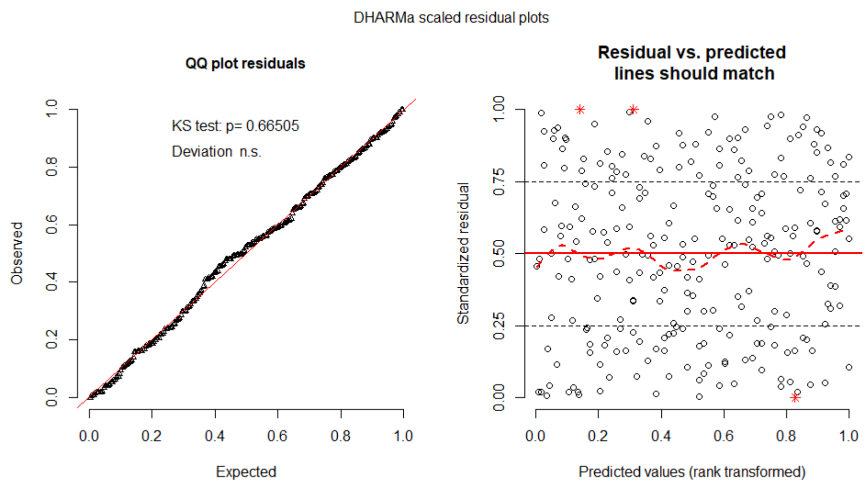


Figure 7. Nominal index (grey circles) of American eel for lower St. Lawrence trap net fisheries (kg per m).



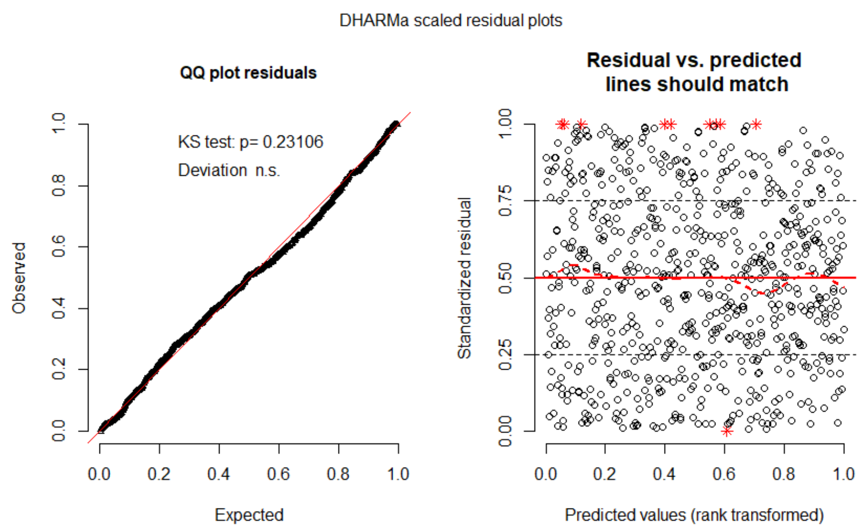


Figure 8. Goodness of fit plots of the final model retained to standardize American eel CPUE in a) fyke net and b) spear fisheries in Nova Scotia (Southern Gulf of St. Lawrence).

Figure 9. American eel abundance indices for winter spearing (kg of legal sized eels per spear-hour) and fyke net (kg of legal sized eels per net per day) fisheries in Nova Scotia (Southern Gulf of St. Lawrence). The nominal index is denoted by grey circles while abundance indices and confidence intervals are indicated in green.

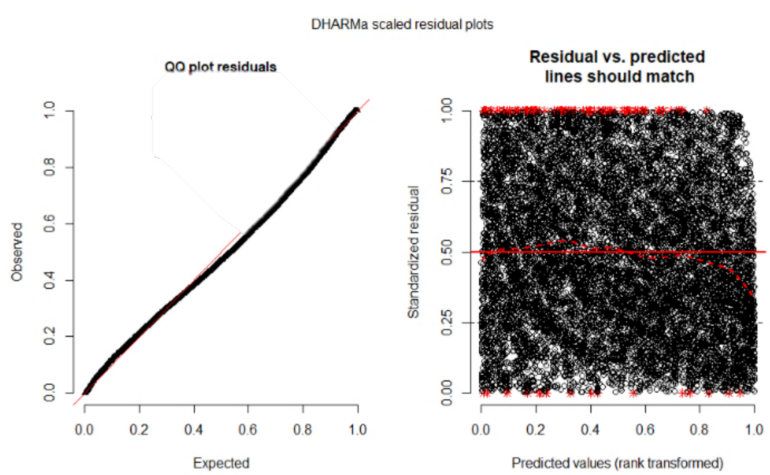


Figure 10. Goodness of fit plots of the final model retained to standardize American eel CPUE in fyke net fisheries in Prince Edward Island, Southern Gulf of St. Lawrence.

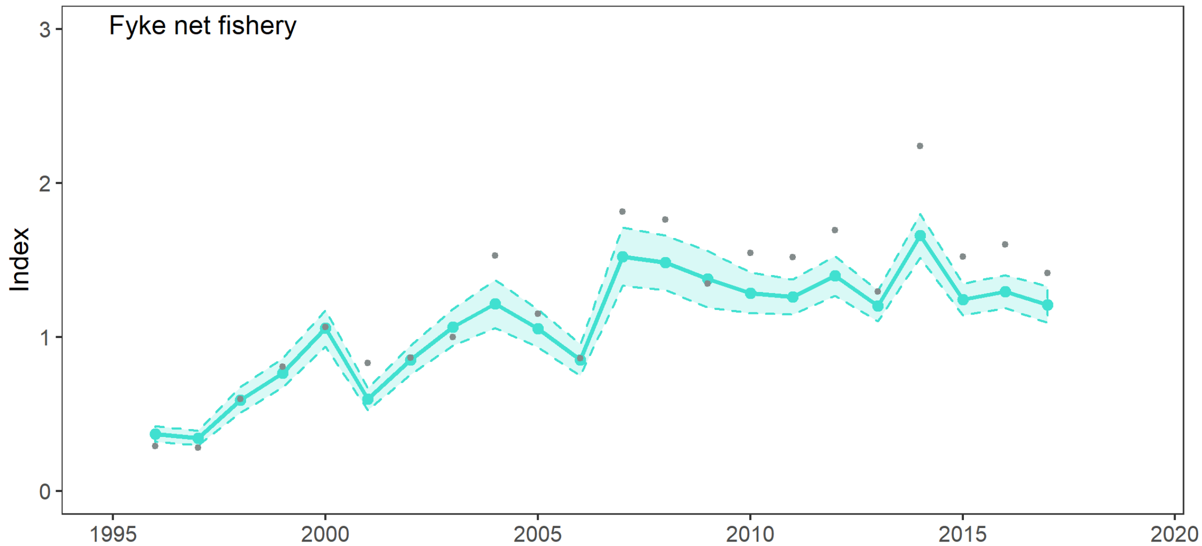


Figure 11. Abundance index of American eel for fyke net fisheries (kg of legal sized eels per net per day) in Prince Edward Island, Southern Gulf of St. Lawrence. The nominal index is denoted by grey circles while the abundance index and the confidence interval are indicated in green.

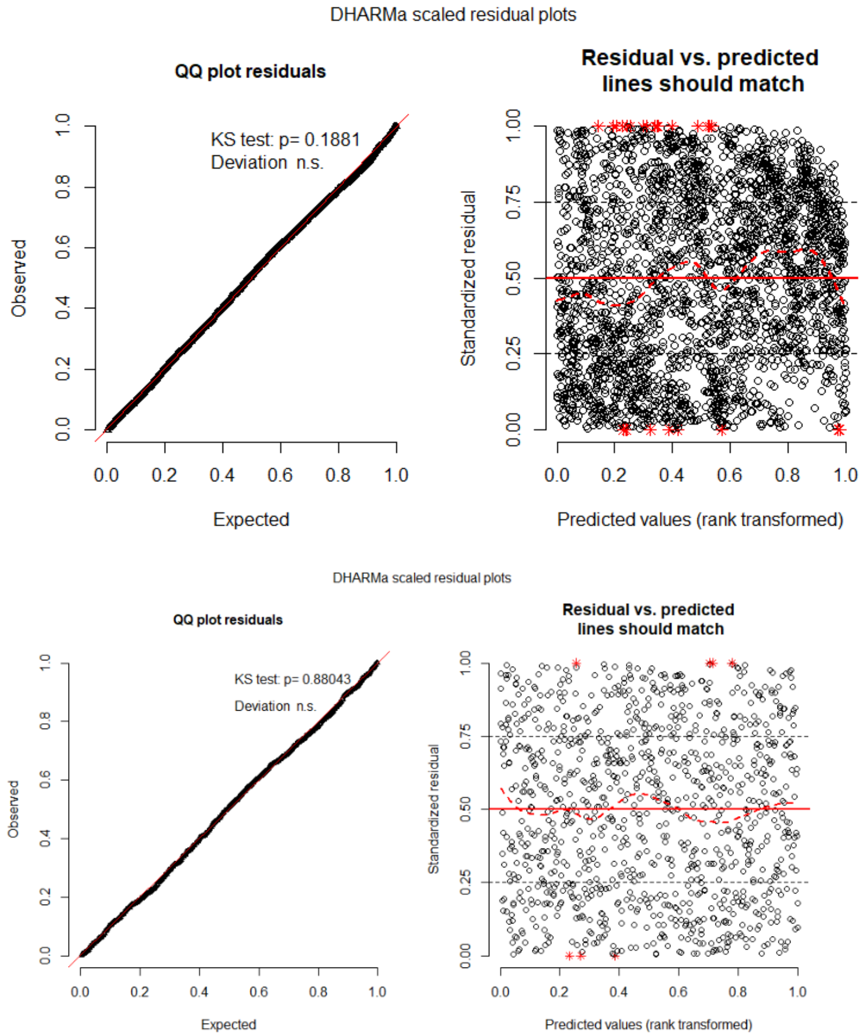


Figure 12. Goodness of fit plots of the final model retained to standardize American eel abundance in the St. Lawrence Basin (Ontario): a) the Saunders ladder of the Moses-Saunders Dam and b) Bay of Quinte.

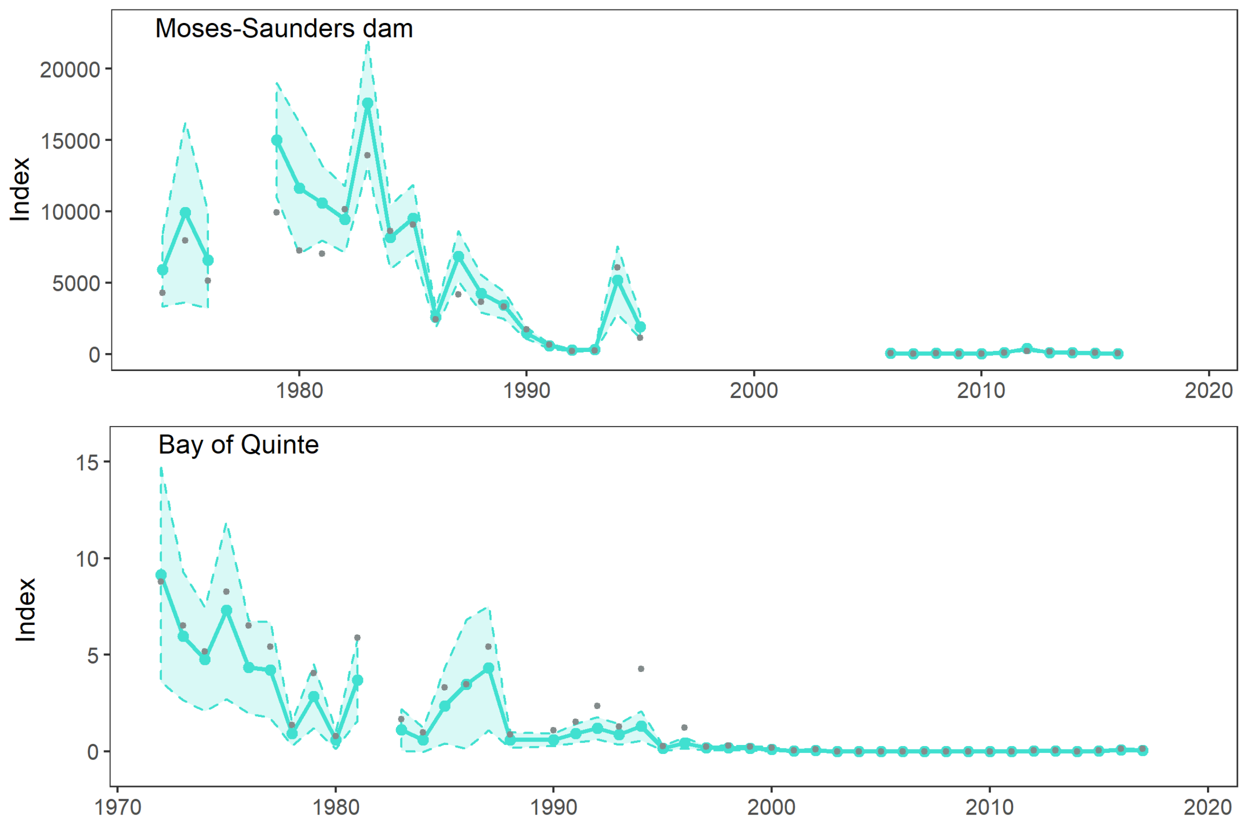


Figure 13. Abundance index for American eel in the St. Lawrence Basin (Ontario) from the Saunders ladder of the Moses-Saunders Dam (eels per day) and Bay of Quinte (eels 100m^{-2}). Nominal index is denoted by grey circles while abundance index and confidence interval are indicated in green.

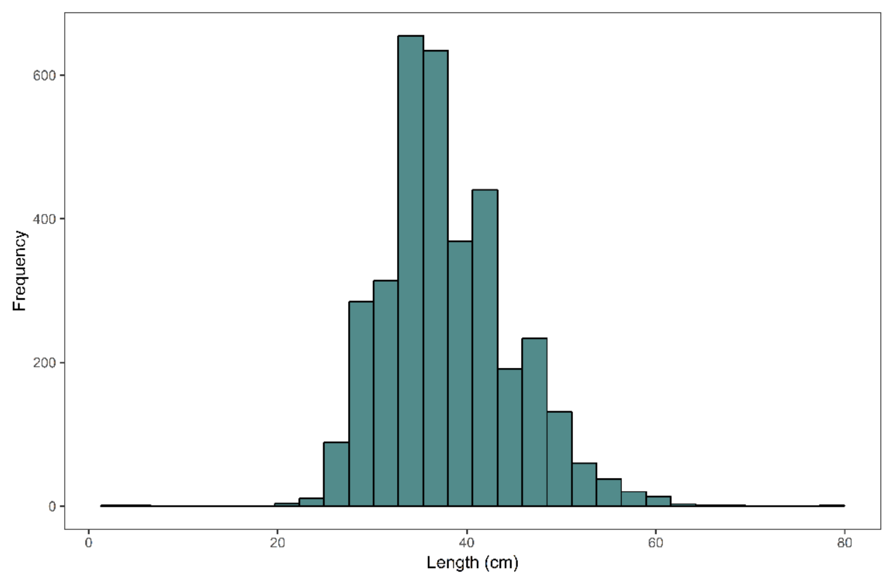


Figure 14. Length frequency of American eels at the Moses-Saunders Dam from 2006 to 2018.

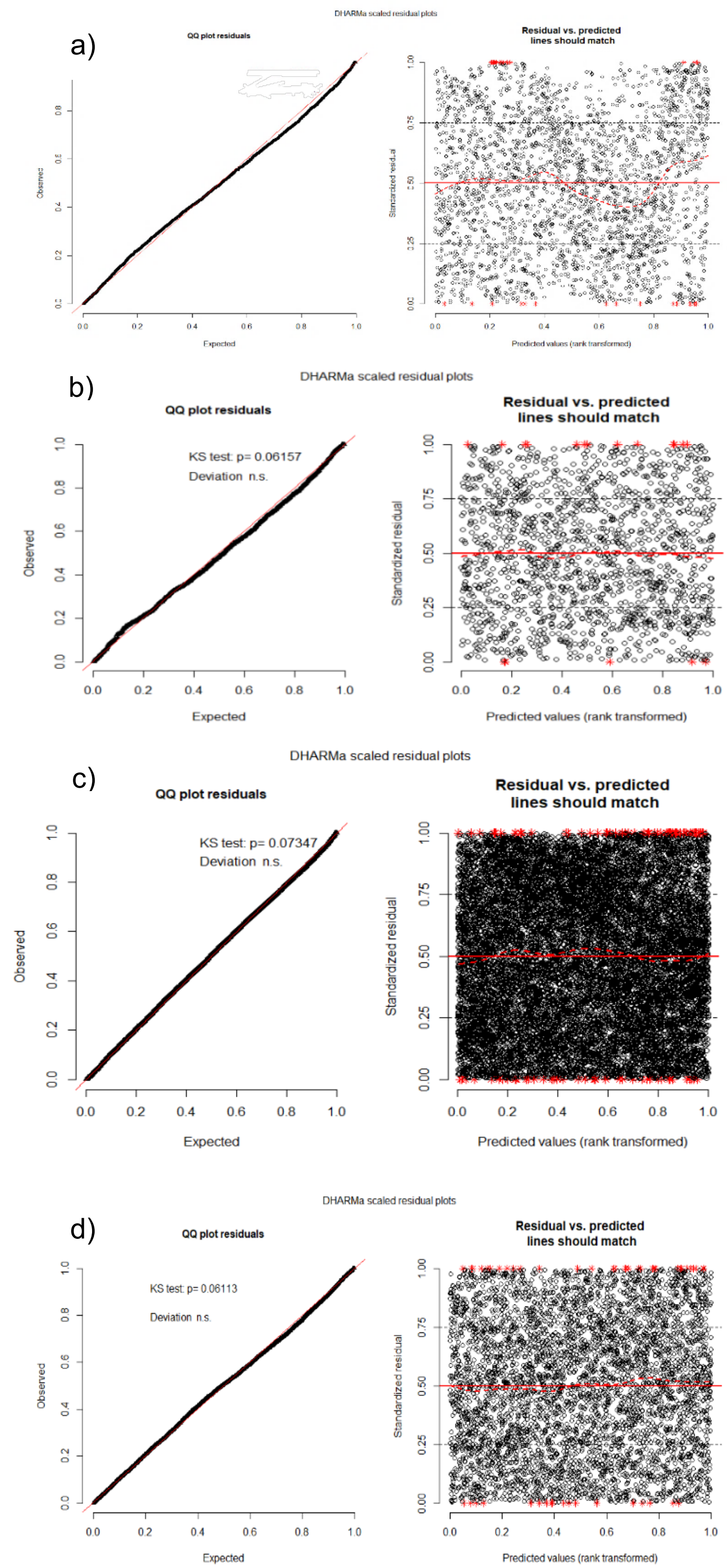


Figure 15. Goodness of fit plots of the final model retained to standardize American eel abundance in the St. Lawrence Basin: a) Beauharnois Dam, b) Chambly Dam, c) Saint Nicolas trap (May to October), and d) Saint Nicolas trap (September-October).

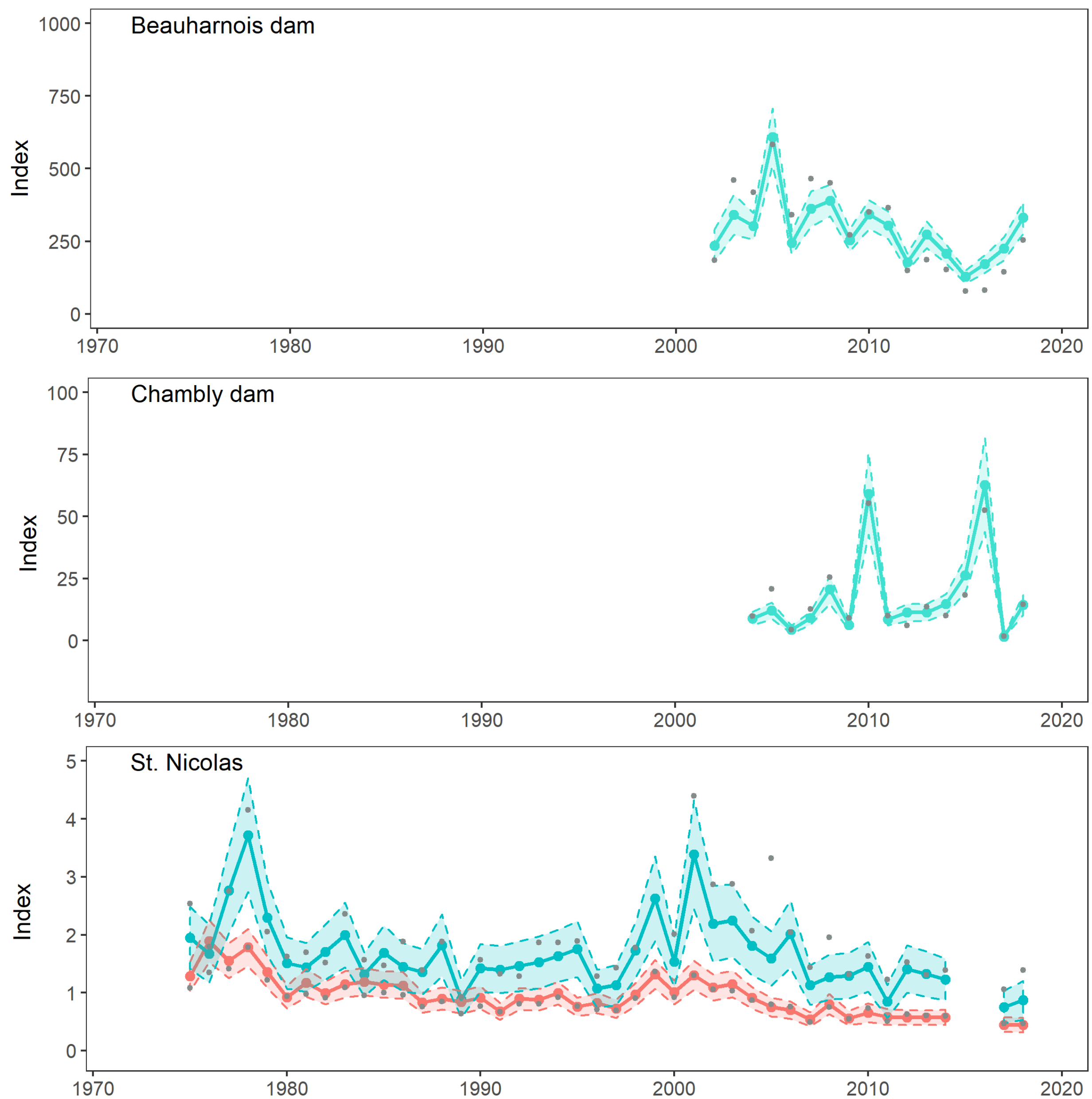


Figure 16. Abundance index for American eel in the St. Lawrence Basin in Quebec from the Beauharnois Dam (eels per day), the Chambly Dam (eels per day), and the Saint Nicolas trap (eels per tidal cycle). The nominal index is denoted by grey circles while the abundance index and confidence interval are indicated in green. For Saint Nicolas, green indicates the index corresponding to silver eel catches (September-October) and orange indicates the index corresponding to a mix of yellow and silver eel catches (May-October).

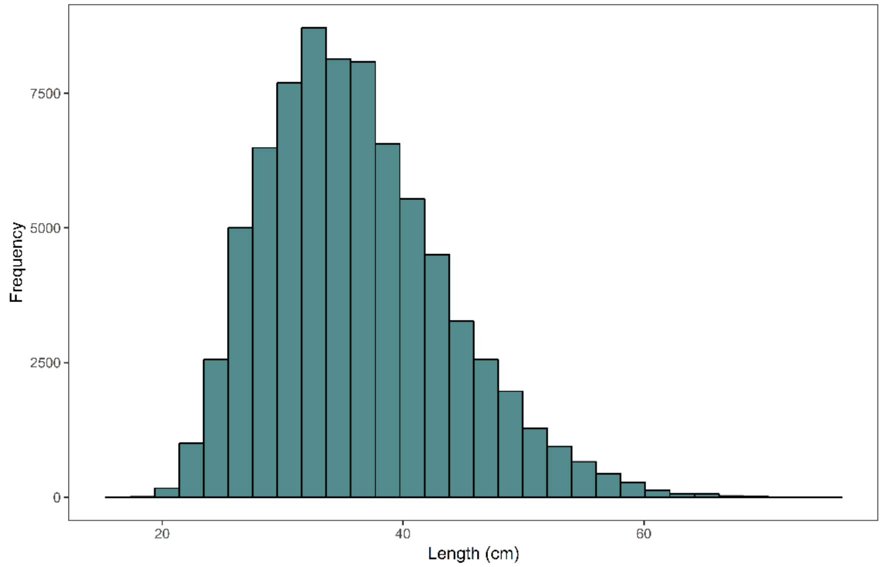


Figure 17. Length frequency of American eel at Beauharnois Dam from 2002 to 2018.

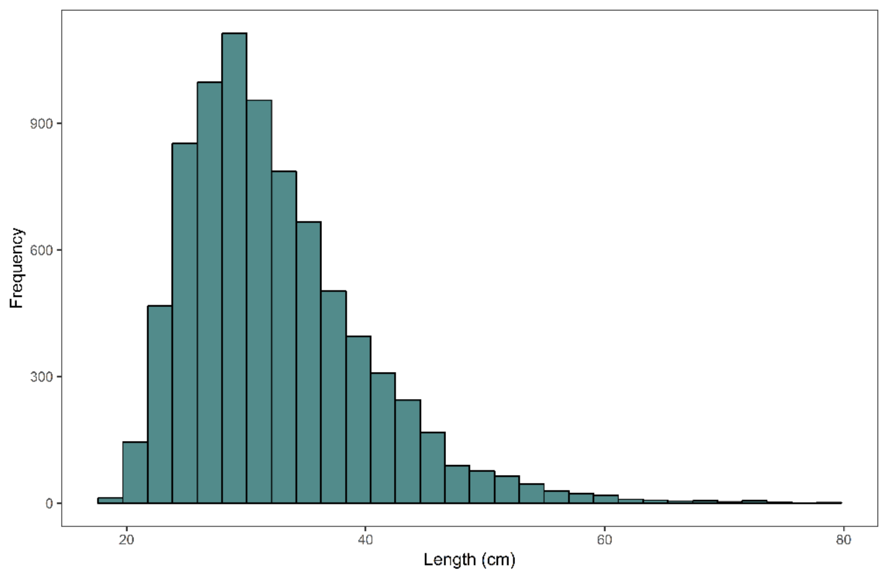


Figure 18. Length frequency of American eel at the west pass of Chambly Dam from 2006 to 2018.

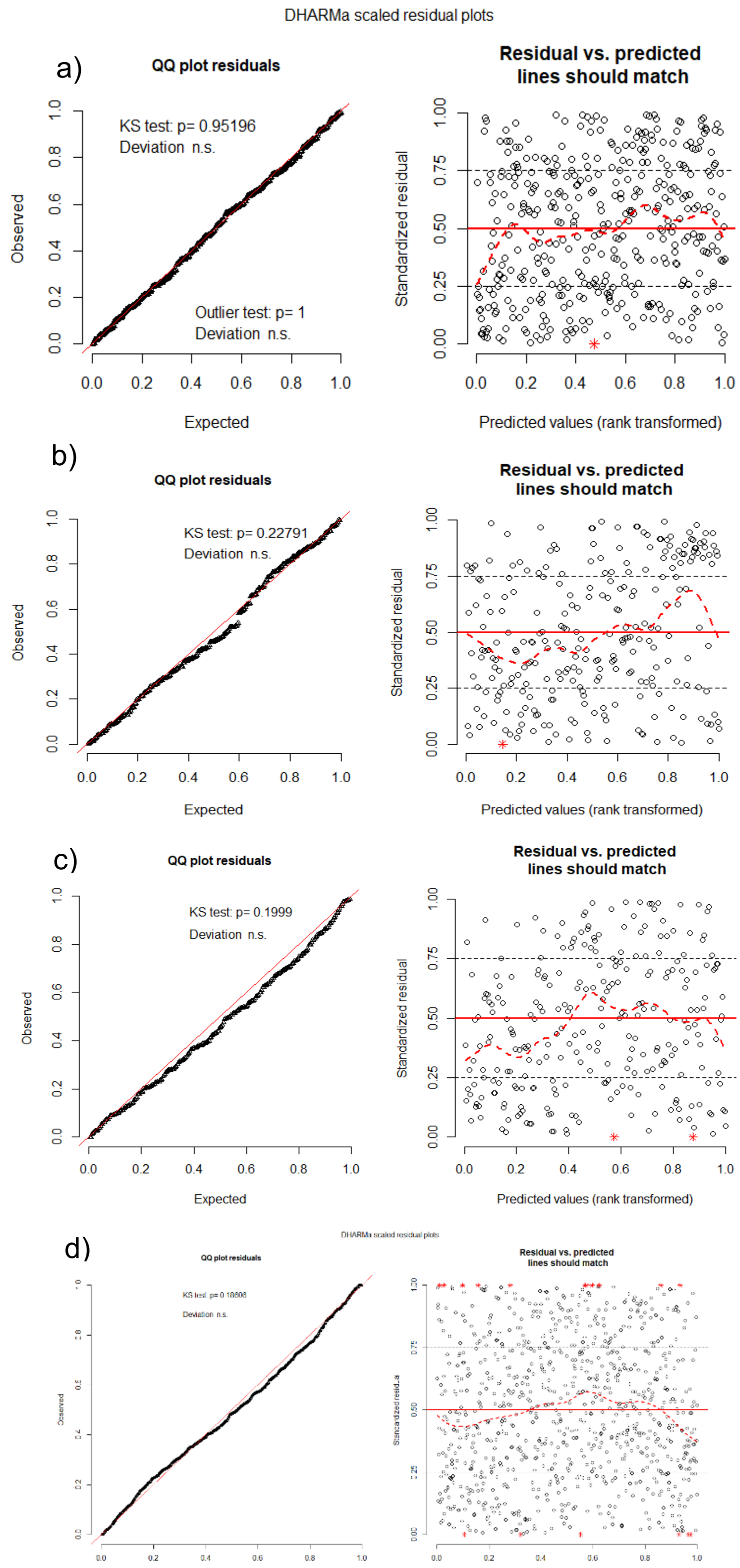


Figure 19. Goodness of fit plots of the final model retained to standardize American eel abundance in Scotia-Fundy: a) Nashwaak River, b) LaHave River, c) St. Marys River, and d) all rivers combined.

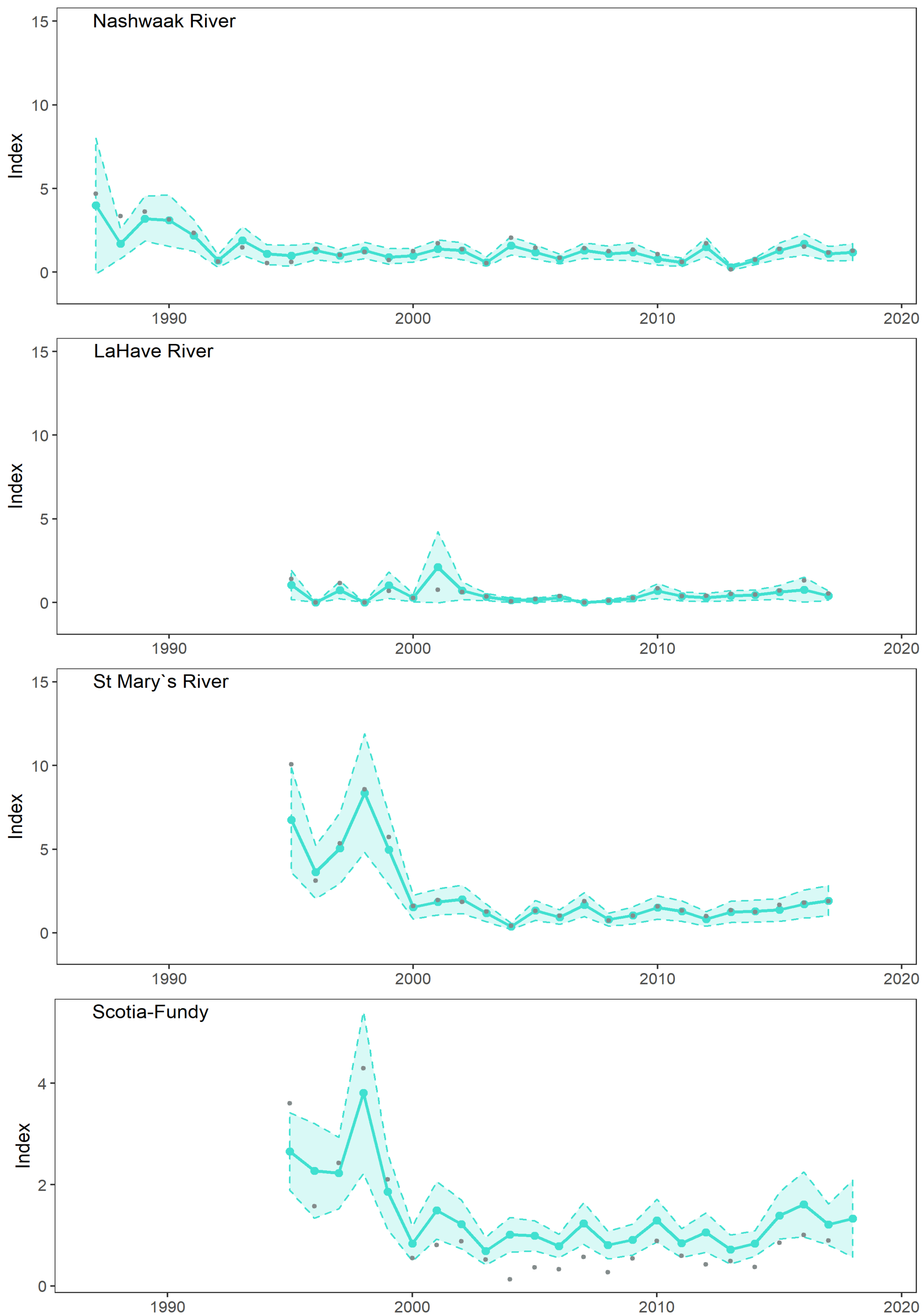


Figure 20. Abundance indices for American eel (eels 100m^{-2} in the first electrofishing pass) in Scotia-Fundy from electrofishing surveys in the Nashwaak River, the LaHave River, the St. Marys River, and all rivers combined. The nominal index is denoted by grey circles while the abundance index and confidence interval are indicated in green.

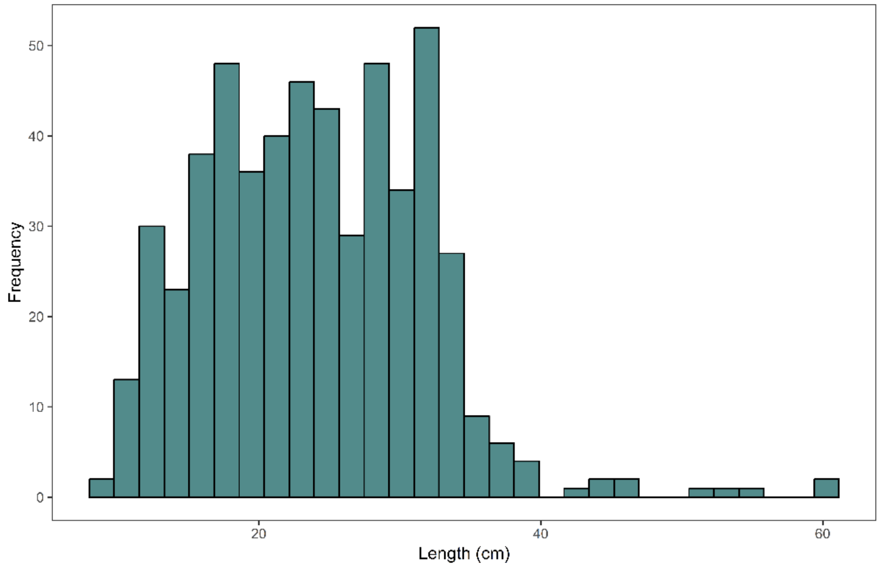


Figure 21. Length frequency of American eel in the Nashwaak River from 2013 to 2018. Note that the length was not recorded with the same method in 2013 (n=50, average 24.7cm) and 2017 (n=85, average 24.4 cm).

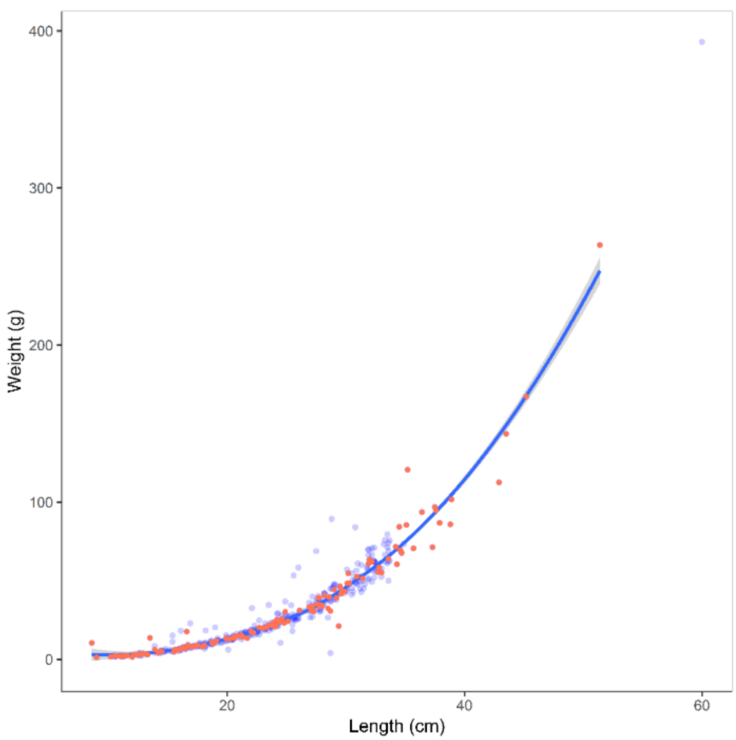


Figure 22. Length-weight relationship of American eel in the Nashwaak River (Scotia-Fundy) from 2013 to 2018.

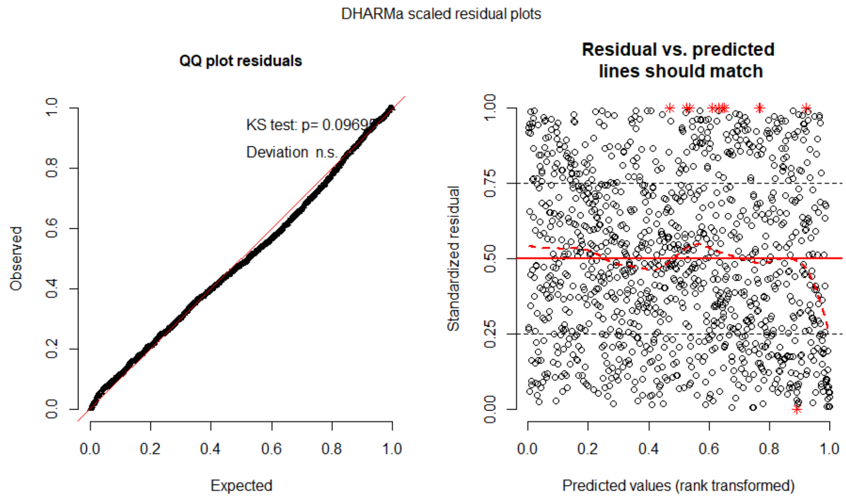


Figure 23. Goodness of fit plots of the final model retained to standardize American eel elver abundance in Nova Scotia (Scotia-Fundy).

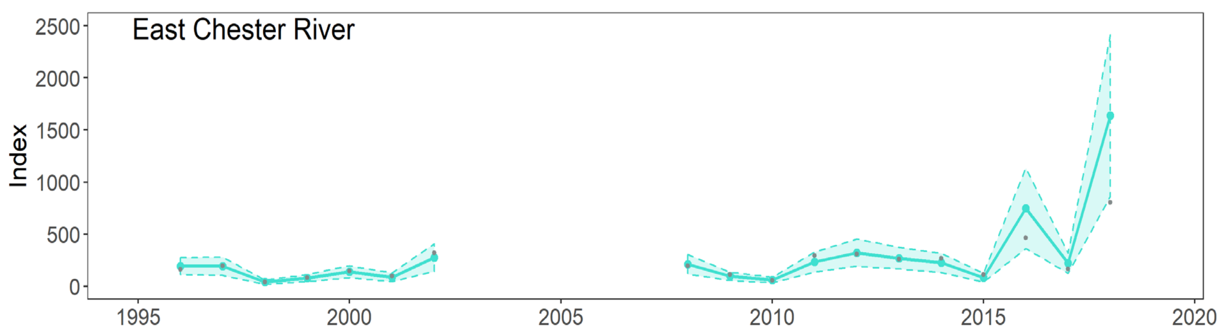


Figure 24. Abundance index for elvers (kg per day) in Nova Scotia (Scotia-Fundy) from trap surveys. The nominal index is denoted by grey circles while the abundance index and confidence interval are indicated in green.

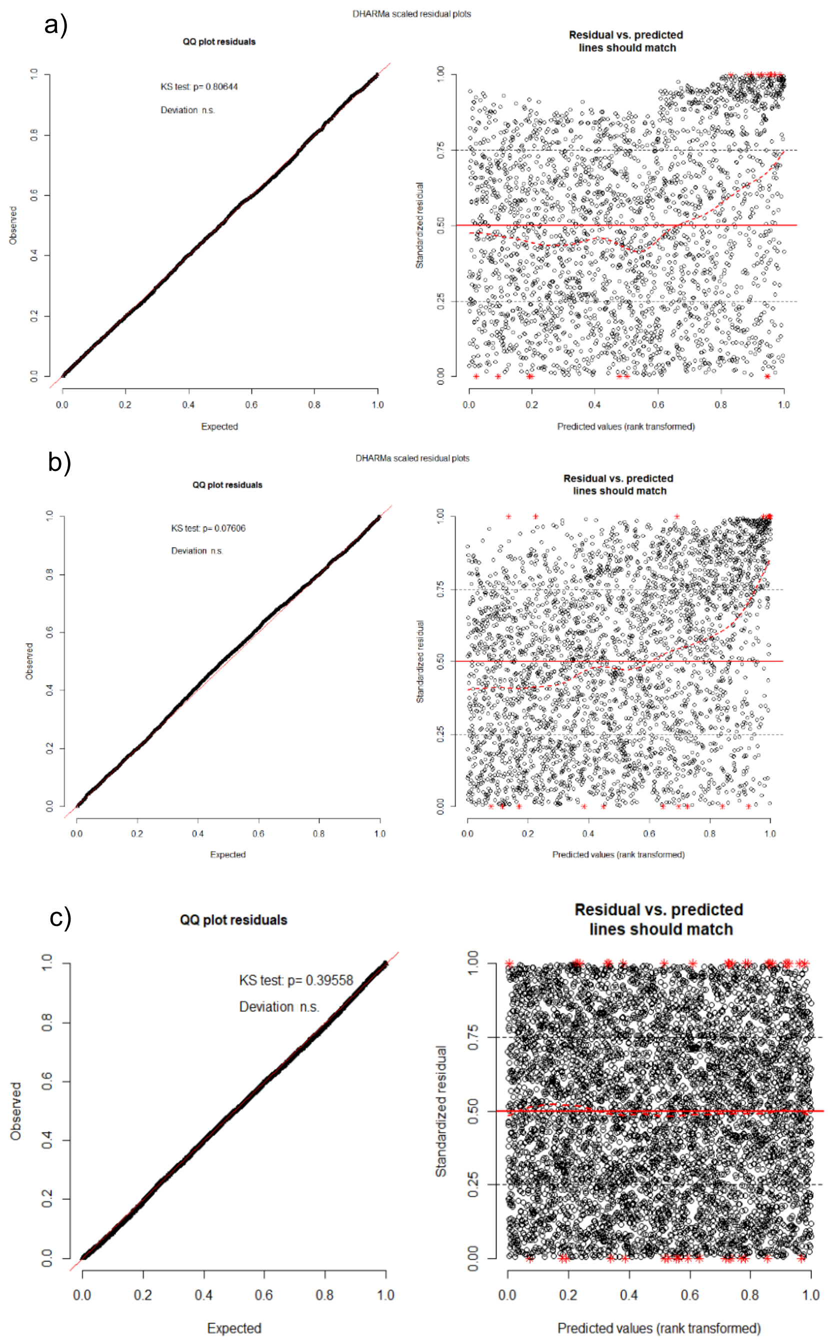


Figure 25. Goodness of fit plots of the final model retained to standardize American eel abundance in the Southern Gulf of St. Lawrence: a) Restigouche River, b) Miramichi River, and c) all rivers combined.

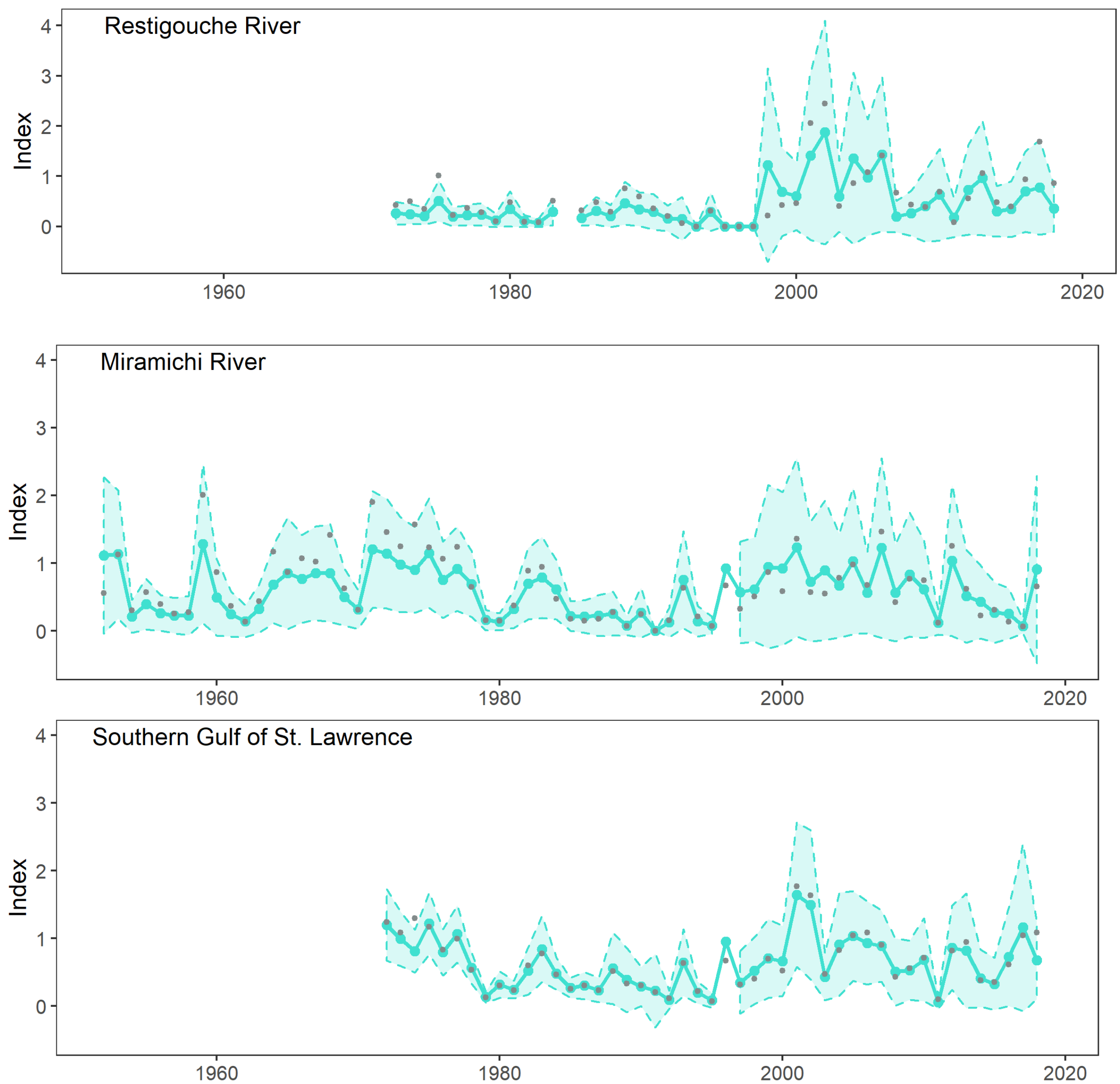


Figure 26. Abundance index for American eel (eels 100m^{-2}) in the Southern Gulf of St. Lawrence from electrofishing surveys. The bottom panel represents the abundance index for the Restigouche River and Miramichi River combined. The nominal index is denoted by grey circles while the abundance index and confidence interval are indicated in green.

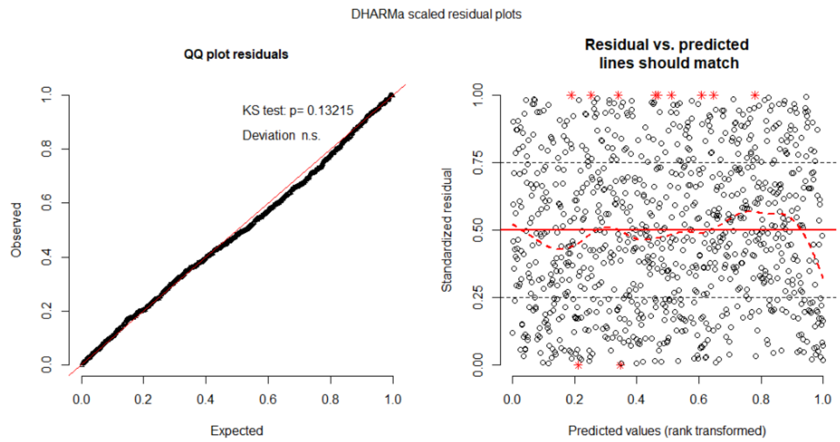


Figure 27. Goodness of fit plots of the final model retained to standardize American eel abundance in the Northern Gulf from Sud-Ouest River trapnet surveys.

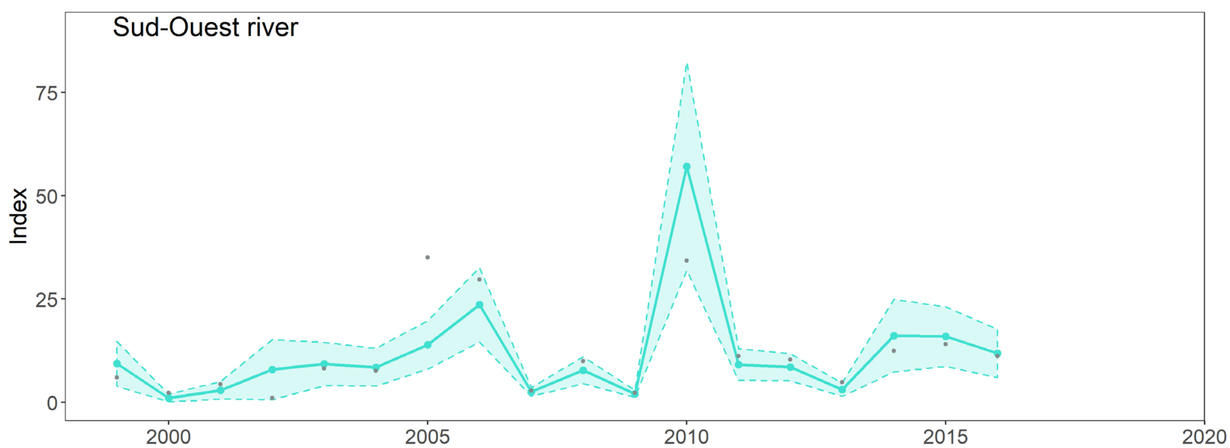


Figure 28. Abundance index for American eel (eels per day) in the Northern Gulf. The nominal index is denoted by grey circles while the abundance index and confidence interval are indicated in green.

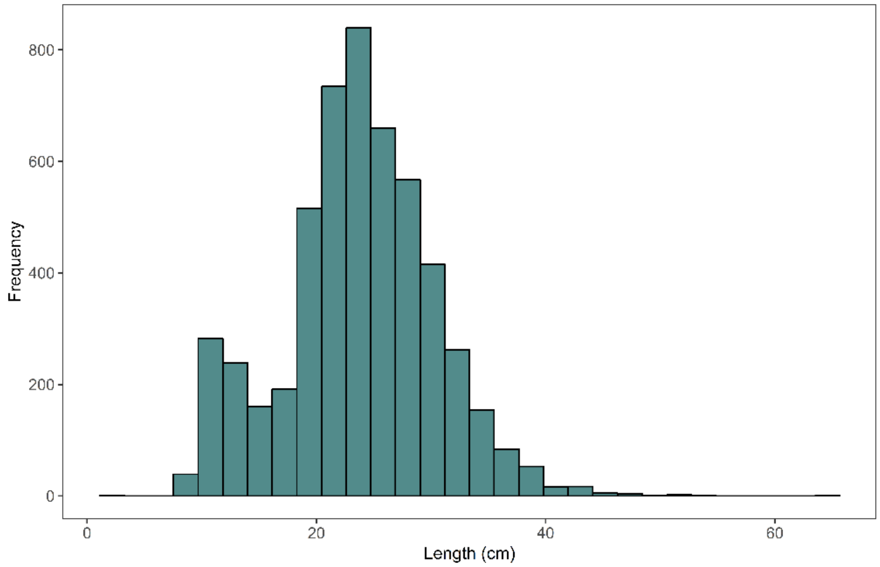


Figure 29. Length frequency of American eel in the Sud-Ouest River from 2004 to 2014.

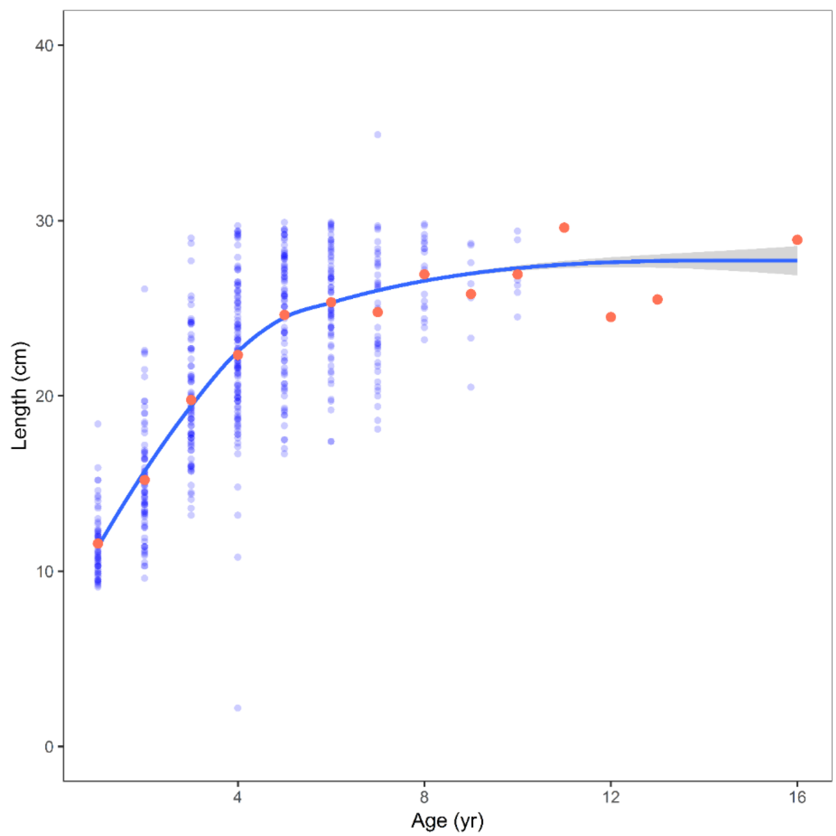


Figure 30. Length-age relationship of American eel in the Sud-Ouest River (Quebec), 2004 to 2013.

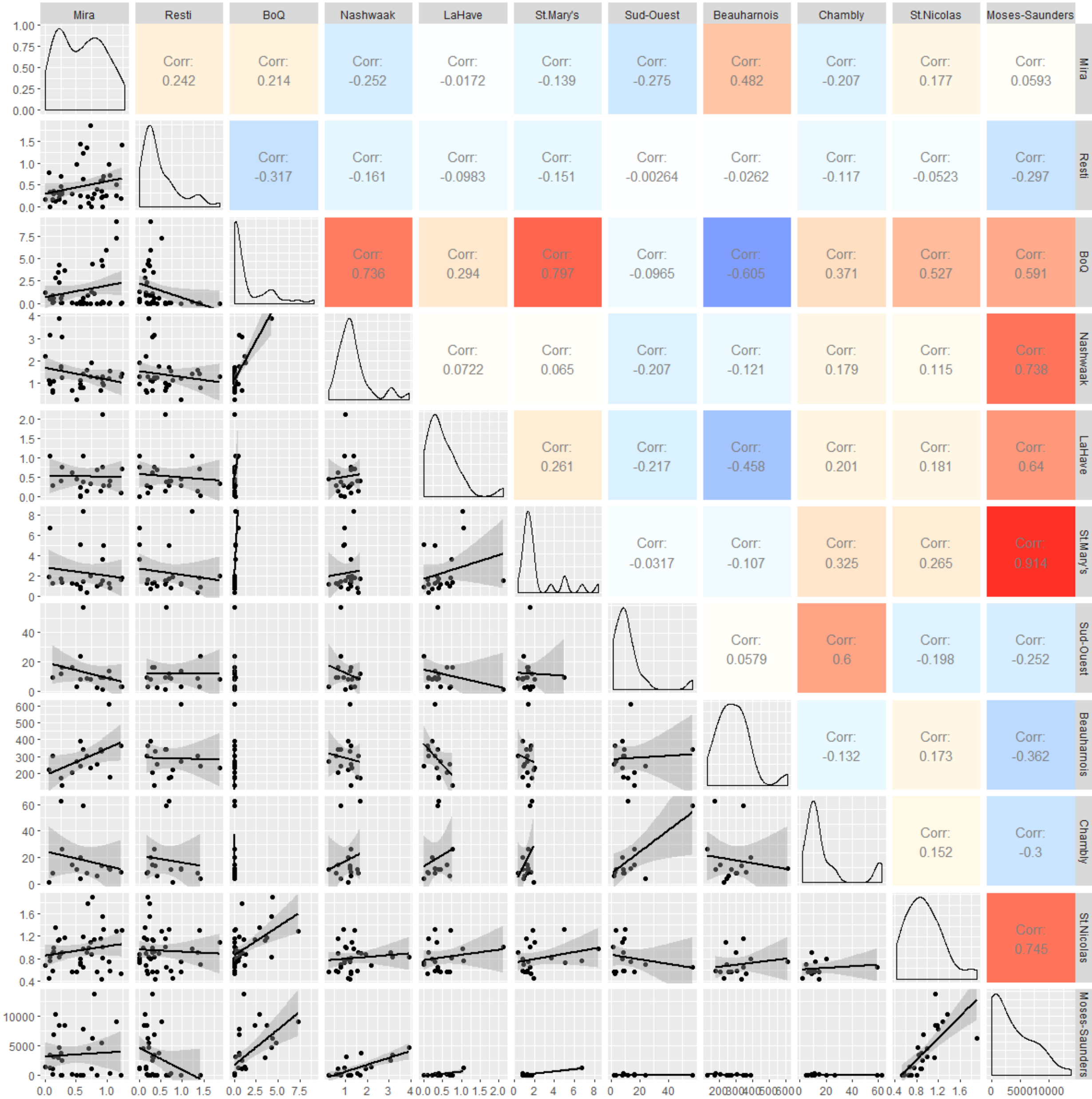


Figure 31. Spearman correlation matrix for fishery-independent abundance indices. The scale of the colors is denoted as follows: the more positive the correlation (closer to 1) the darker the shade of red; the more negative the correlation (closer to −1) the darker the shade of blue.

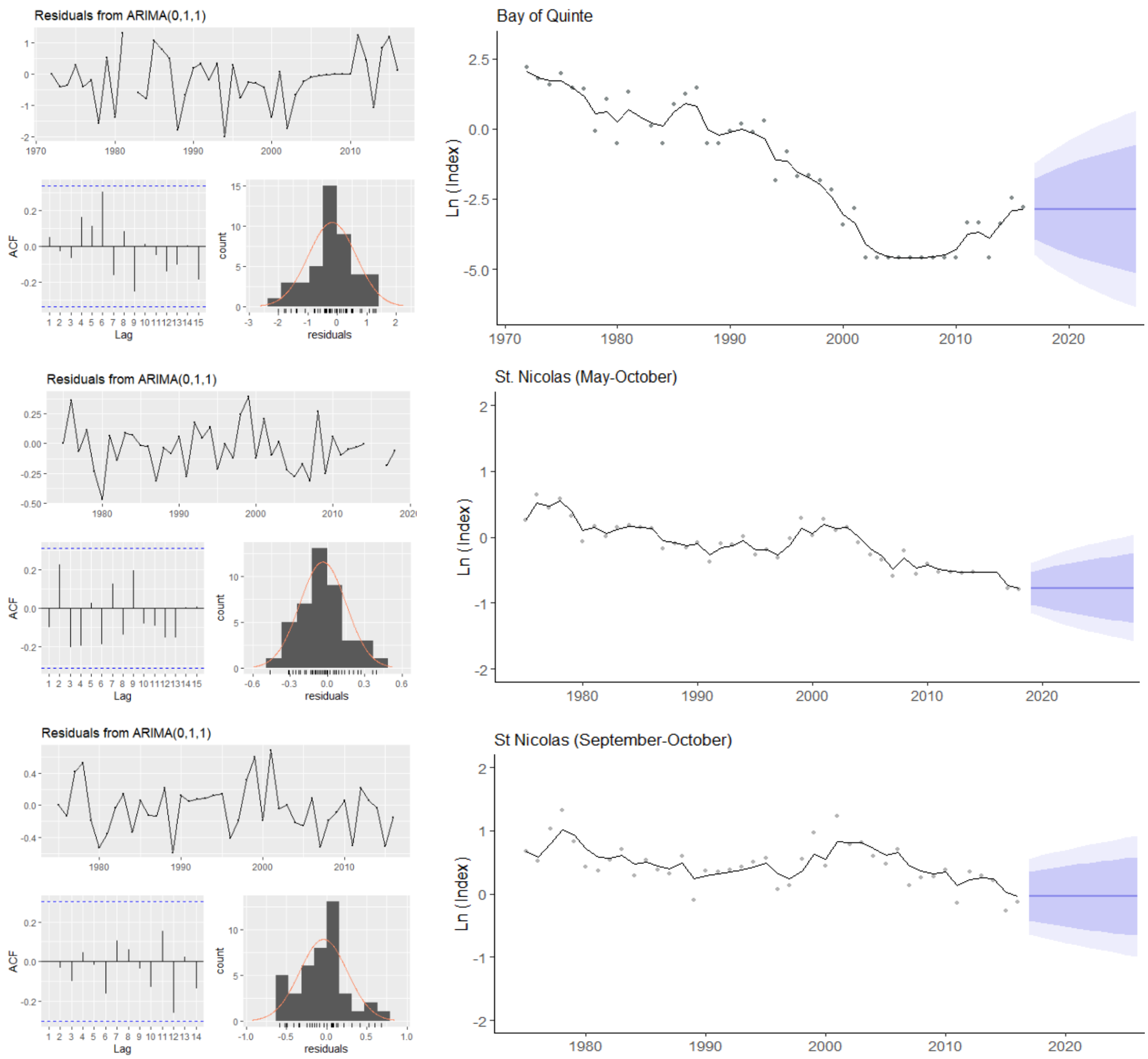


Figure 32. Residual diagnostics and ARIMA models of American eel abundance indices in the St. Lawrence Basin. Blue lines represent the projection of American eel abundance for the next ten years and blue shades their confidence intervals (80% in dark shade and 95% in light shade).

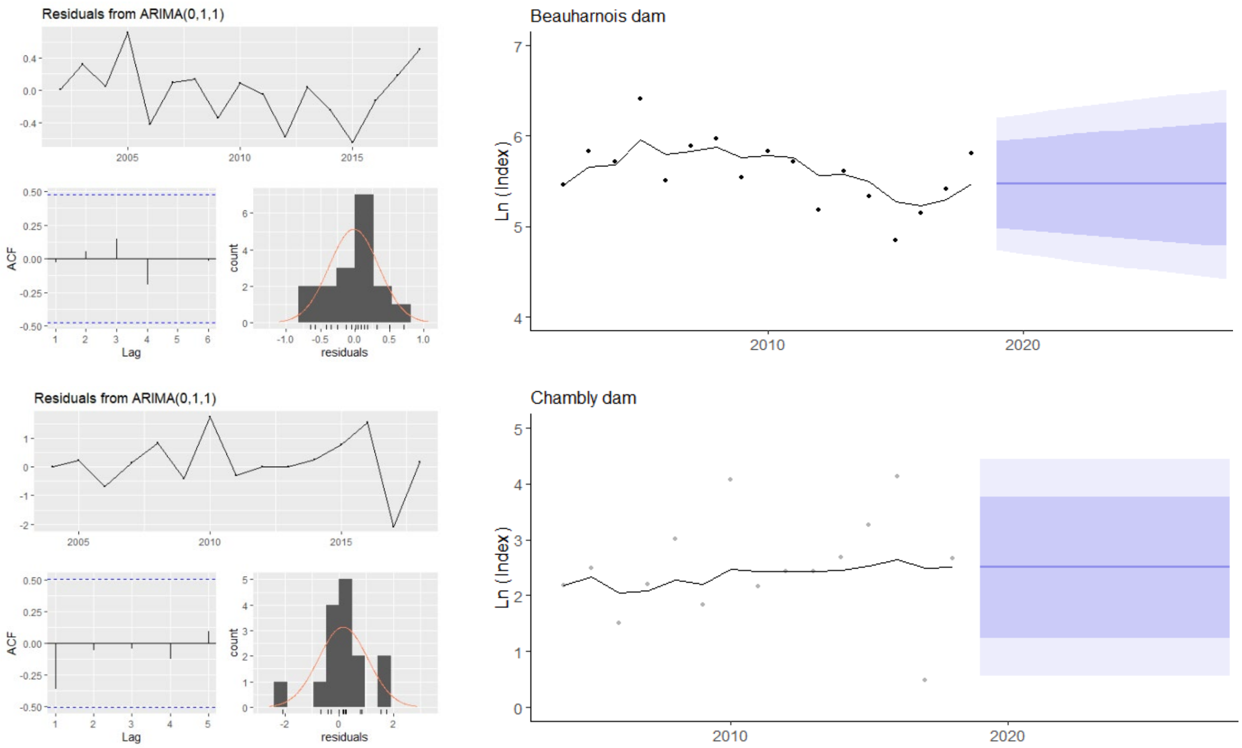


Figure 32 (continued).

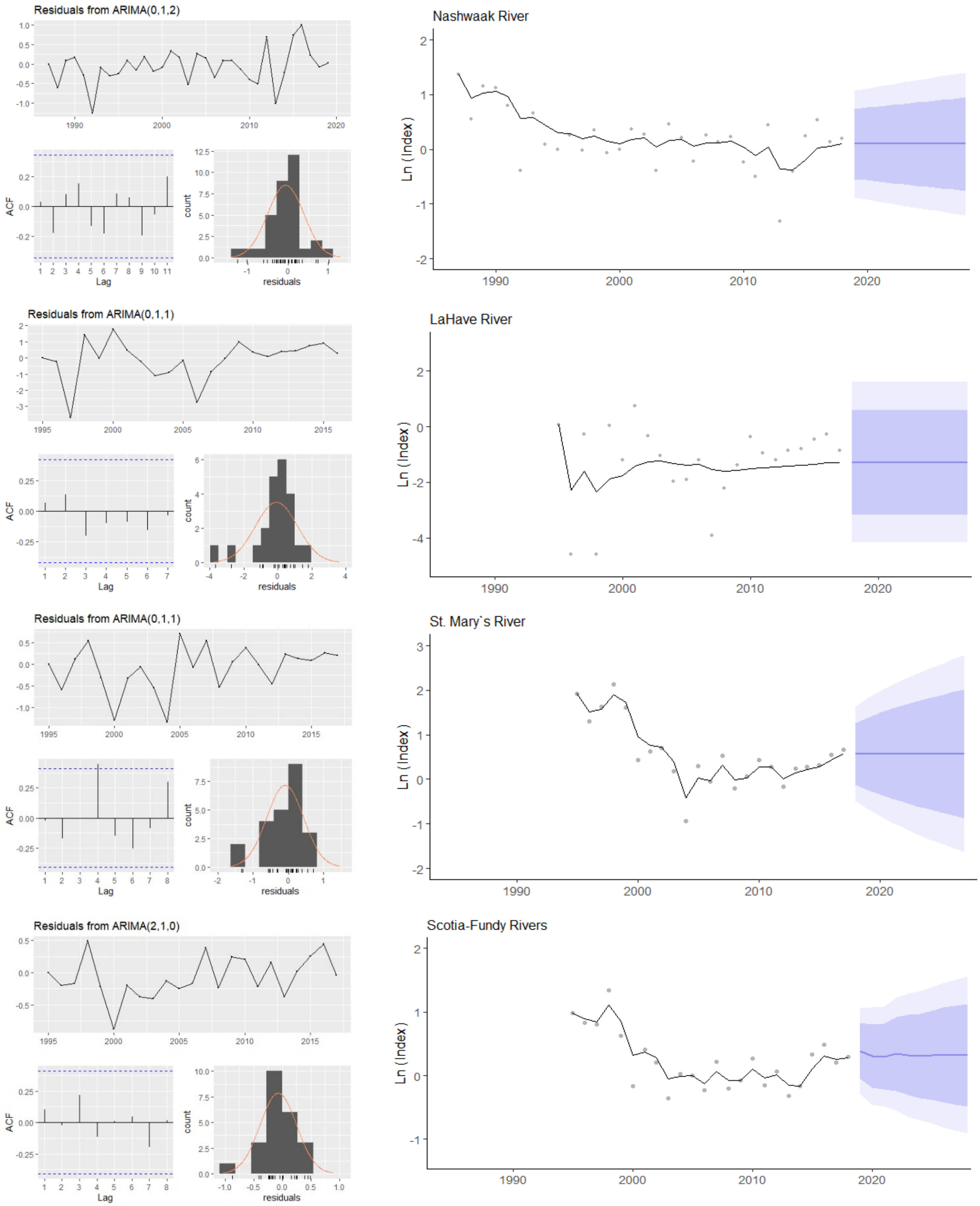


Figure 33. Residual diagnostics and ARIMA models of American eel abundance indices in Scotia-Fundy. Blue lines represent the projection of American eel abundance for the next ten years and blue shades their confidence intervals (80% in dark shade and 95% in light shade).

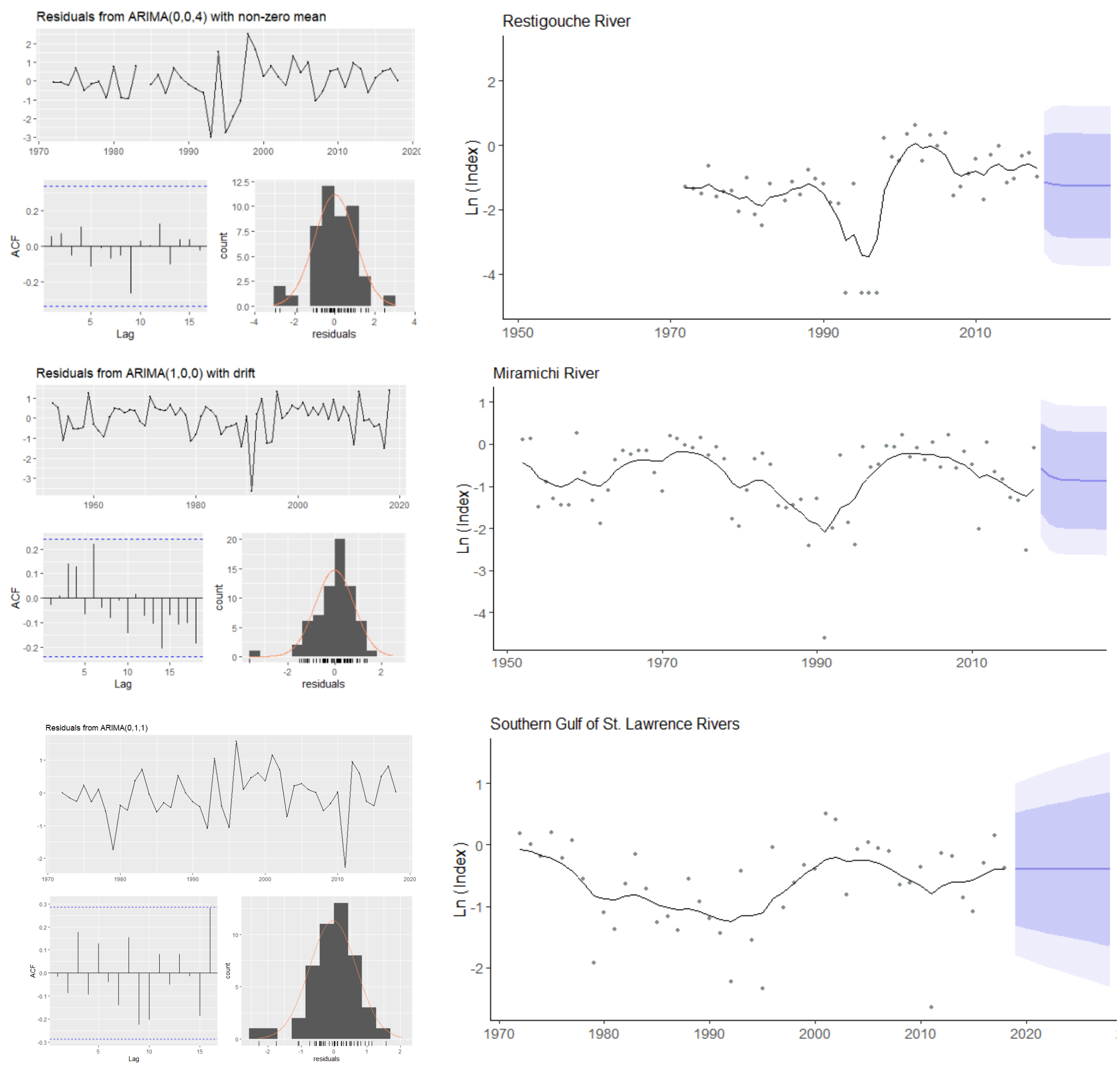


Figure 34. Residual diagnostics and ARIMA models of American eel abundance indices in the Southern Gulf of St. Lawrence. Blue lines represent the projection of American eel abundance for the next ten years and blue shades their confidence intervals (80% in dark shade and 95% in light shade).

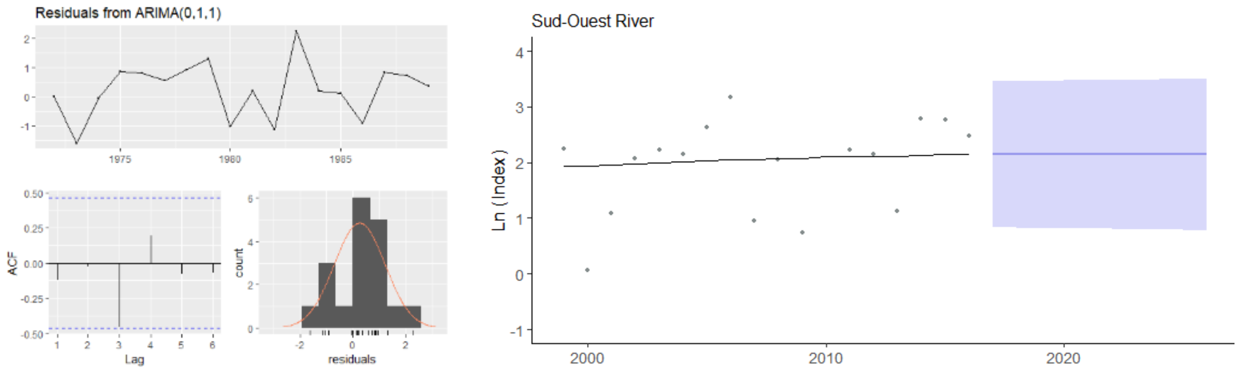


Figure 35. Residual diagnostics and ARIMA models of American eel abundance indices in the Northern Gulf of St. Lawrence. Blue lines represent the projection of American eel abundance for the next ten years and blue shades their confidence intervals (80% in dark shade and 95% in light shade).