Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S | **S C C S**

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2011/050 | **Document de recherche 2011/050**

Central and Arctic Region | **Région du Centre et de l’Arctique**

2010 Update on the status of American Eel (*Anguilla rostrata*) in Ontario

Mise à jour de 2010 sur l’état de l’anguille d’Amérique (*Anguilla rostrata*) en Ontario

T.C. Pratt[1] and A. Mathers[2]

[1]Fisheries and Oceans Canada, 1219 Queen St East, Sault Ste Marie, ON, P6A 2E5
thomas.pratt@dfo-mpo.gc.ca
[2]Ministry of Natural Resources, RR4, Picton, ON K0K 2T0
alastair.mathers@ontario.ca

ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Correct citation for this publication:

Pratt, T.C. and A. Mathers. 2011. 2010 Update on the status of American Eel (*Anguilla rostrata*) in Ontario. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/050. vi + 18 p.

ABSTRACT

American Eel (*Anguilla rostrata*) once comprised an important component of the fish community, and supported significant commercial fisheries, in the Ottawa River and Lake Ontario / upper St. Lawrence River watersheds in the Province of Ontario. These eels were large, fecund females, and it is estimated that eels from these watersheds comprised over 50% of the potential fecundity from Canadian waters. Today, eel recruitment to Ontario waters has declined by approximately 97% since the early 1980s. A slight rebound in recruitment is apparent since 2004. Two fisheries-independent yellow eel abundance indices show similar declines over the same timeframe, and the species is now listed as Endangered under the province's *Endangered Species Act* (2007). Restrictions to rearing habitat access have resulted in significant lost production potential, estimated to be over 250,000 silver eels from the Ottawa River watershed alone. Recovery of abundance and distribution within the waters of Ontario will depend on improved production and enhanced density-dependent dispersal of recruits from the Sargasso Sea. Therefore, threats that occur outside of Ontario are as important as threats from within the province. Potential threats include harvesting, loss of habitat access, habitat alteration, productivity and food webs alterations, turbine mortality, parasites, and toxins and contaminants.

RÉSUMÉ

L'anguille d'Amérique (*Anguilla rostrata*) a déjà constitué un élément important de la communauté de poissons et compté de façon importante pour les pêcheries commerciales dans la rivière des Outaouais et dans les bassins hydrographiques du lac Ontario/de la partie supérieure du fleuve Saint-Laurent dans la province de l'Ontario. Ces anguilles étaient de grosses femelles fécondes et l'on estime que les anguilles de ces bassins hydrographiques comptaient pour plus de 50 p. 100 du potentiel de fécondité dans les eaux canadiennes. De nos jours, le recrutement d'anguilles dans les eaux ontariennes a connu une baisse d'environ 97 p. 100 depuis le début des années 1980. On constate une légère reprise du taux de recrutement depuis 2004. Deux indices d'abondance de l'anguille jaune, n'ayant aucun lien avec les pêcheries, indiquent un déclin semblable pour la même période et l'espèce est maintenant inscrite comme étant en voie de disparition en vertu de la *Loi sur les espèces en voie de disparition* (2007) de la province. Les restrictions pour l'accès à l'habitat de grossissement ont entraîné un important potentiel de perte de production, estimé à plus de 250 000 anguilles argentées uniquement pour le bassin hydrographique de la rivière des Outaouais. Le rétablissement de l'abondance et de la répartition dans les eaux ontariennes dépendra de l'amélioration de la production et de la dispersion accrue des recrues de la mer des Sargasses selon la densité. Par conséquent, les menaces qui se manifestent à l'extérieur de l'Ontario sont aussi importantes que les menaces à l'intérieur de la province. Les menaces possibles comprennent la pêche, la perte d'accès à l'habitat, la perturbation de l'habitat, les perturbations pour la productivité et la chaîne trophique, les mortalités dues aux turbines, les parasites, ainsi que les toxines et les contaminants.

INTRODUCTION

American Eel (*Anguilla rostrata*) have one of the most complex life history strategies of any of the North American fishes (Figure 1). They are semelparous, tolerate a wide range of temperatures and salinities, and exhibit facultative catadromy (Jessop et al. 2002, Tesch 2003, Thibault et al. 2007). Found in coastal, brackish and freshwater systems from Venezuela to Greenland (Helfman et al. 1987, Tesch 2003), eels from across this wide geographic range are panmictic (comprise a single breeding population) (Avise 2003). Spawning-phase silver eels migrate to the Sargasso Sea to spawn and die. Larval stage leptocephali are transported on oceanic currents for up to one year reaching roughly 60mm in length, after which they reach continental waters and metamorphose into glass eels. As glass eels initiate feeding they progressively become more pigmented and are termed elvers. After a few months they become fully pigmented and are termed yellow eels. The yellow eel stage can last from 4 to greater than 25 years, with residency times generally increasing with increasing latitude (Vélez-Espino and Koops 2009).

By the time inland migrating eels reach the Province of Ontario via the St. Lawrence River they are, on average, 6-9 year old yellow eels. Near the northern end of the species' range, American Eels in Ontario use lakes and rivers as nursery habitat. Preceding spawning migration a final metamorphosis event occurs and eels transition into the sexually mature, non-feeding silver eel phase. Fully mature silver eels do not naturally occur in Ontario however, fish displaying the early stages of sexual maturity have been identified (McGrath et al. 2003, Tremblay 2009).

The American Eel is sexually dimorphic in growth, maturation, and distribution, with females growing larger and maturing later than males (Helfman et al. 1987, Oliviera and McCleave 2002). Males are more commonly produced in southern latitudes, while the reverse is true for females. As best we know, every indigenous eel sexed in Ontario has been a large, highly fecund female (Casselman 2003, MacGregor et al. 2009).

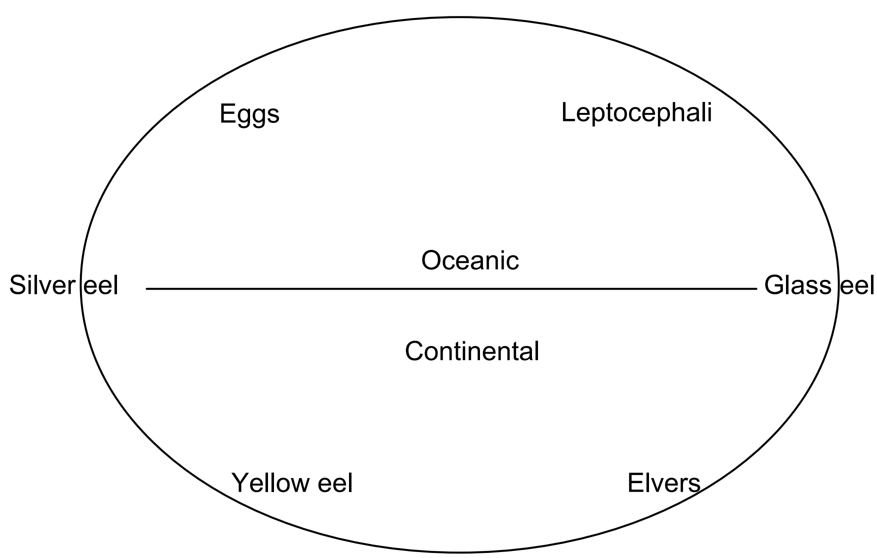

Figure 1. American Eel life cycle. The yellow eel stage can be found in fresh, brackish and salt water.

A precipitous 99% decline in juvenile American Eels ascending the Moses-Saunders generating station (GS) ladder en route to Lake Ontario was recorded between 1983 and the mid-1990s and gave rise to concerns over their abundance in the St. Lawrence River watershed (Casselman 2003, Dekker et al. 2003, MacGregor et al. 2009). As a result American Eel have been recommended for listing as a species of "Special Concern" under the Federal *Species at*

Risk Act (COSEWIC 2006), and listed as “Endangered” under the Ontario *Endangered Species Act* (ESA 2007). COSEWIC wishes to update the status of American Eel in Canada, and this manuscript provides an update on the biology and distribution of the species in Ontario. In particular, we will update 1) recent life history data, 2) abundance trends, 3) habitat requirements and availability, and 4) threats to the species.

1. LIFE HISTORY CHARACTERISTICS OF AMERICAN EEL IN ONTARIO

BIOLOGICAL CHARACTERISTICS

Growth, Age, Fecundity, Energetics

As in the Quebec portion of the St. Lawrence River watershed, American Eels in Ontario are among the largest and oldest over the species range (Table 1). There is evidence for an increasing trend in size and age in resident eels since the 1960s, as demonstrated by the differences between the sizes and ages reported in Hurley (1972) with more recent assessments (Table 1).

Table 1. Mean ages of resident yellow eels from Ontario waters

Source	Location	Length (mm) Length range (mm)	Age (yrs) Age range (yrs)	Notes
Hurley (1972)	Lake Ontario	832 (SD ± 44); 630 - 1044	13.0 (SD ± 1.6) 11 - 18	only fish ≥ age 11 used; eels were collected from 1958 - 1966; n = 129
McGrath et al. (2003)	Lake St. Lawrence	930 (SD ± 50)		data estimated from Figure 3; eels were collected in 1998 - 1999; n = 477
Tremblay (2009)	Lake St. Lawrence	1001 (SD ± 66) 890 - 1120	21 (SD ± 4) 14 - 30	eels were silvering; eels were collected in 2001; n = 30
Stanley (unpubl. data)	Lake Ontario, upper St. Lawrence River	931 (SD ± 90) 734 - 1197		data from 2010 Ontario Power Generation American Eel trap and transport experiment; n = 264
	Lake St. Francis	896 (SD ± 94) 682 - 1161		data from 2010 Ontario Power Generation American Eel trap and transport experiment; n = 1535
Casselman and Marcogliese (2010a)	Ottawa River	718 (SD ± 135) 361 - 1016		eels were collected in 2009

Due to their large size, American Eels in Lake St. Lawrence had the highest absolute fecundity (mean fecundity 14.5 (SD ± 2.5) million oocytes) of the eels examined by Tremblay (2009). These eels also had higher energy levels than similar sized eels from elsewhere in the St. Lawrence system (Tremblay 2009). It has been estimated that, during years of high abundance, eels from the St. Lawrence River (SLR) basin contributed 54–67% of the annual spawn output from Canadian waters (COSEWIC 2006).

Mortality and recruitment rates

No estimates of total or natural mortality are available for Ontario. The commercial American Eel fishery was closed in 2004, and any remaining harvest was stopped when the recreational fishery was closed in 2005. Turbine mortality at the Moses-Saunders GS, located on the upper St. Lawrence River, was estimated at 26.5% (NYPA 1998, Verreault and Dumont 2003). No other estimates of anthropogenic mortality are available.

2. REVIEW OF DESIGNATABLE UNITS

Previous (Avise 2003) and recent (Côté and Bernatchez, pers. comm.) genetic data indicate that American Eel comprise a single, panmictic stock. This interpretation was used in the previous COSEWIC assessment to conclude that only a single designatable unit was present in Canada. Interestingly, in a common garden experiment the same researchers have demonstrated differences in functional genes between glass eels captured in Cape Breton and the St. Lawrence River estuary (Côté et al. 2009, Côté and Bernatchez, pers. comm.). Whether these differences could be used to constitute different designatable units is not clear at this time.

3. REVIEW THE COSEWIC CRITERIA

COSEWIC CRITERION – DECLINING TOTAL POPULATION

a) Summarize population trends

The American Eel ‘recruits’ to Ontario during the yellow eel stage, as it takes a few years to migrate up the St. Lawrence River before entering either the Ottawa or upper St. Lawrence River watersheds. The mean age of eels ascending the ladder has varied between six and twelve years (Figure 2). There is a strong correlation between the length of eels ascending the ladder and their age (r=0.7894, Figure 2). Recent declines in mean ladder size are concurrent with decreases in age. On the Ottawa River, Hurley (1972) estimated the mean age of recruiting yellow eels below the first barrier to be 4.5 years.

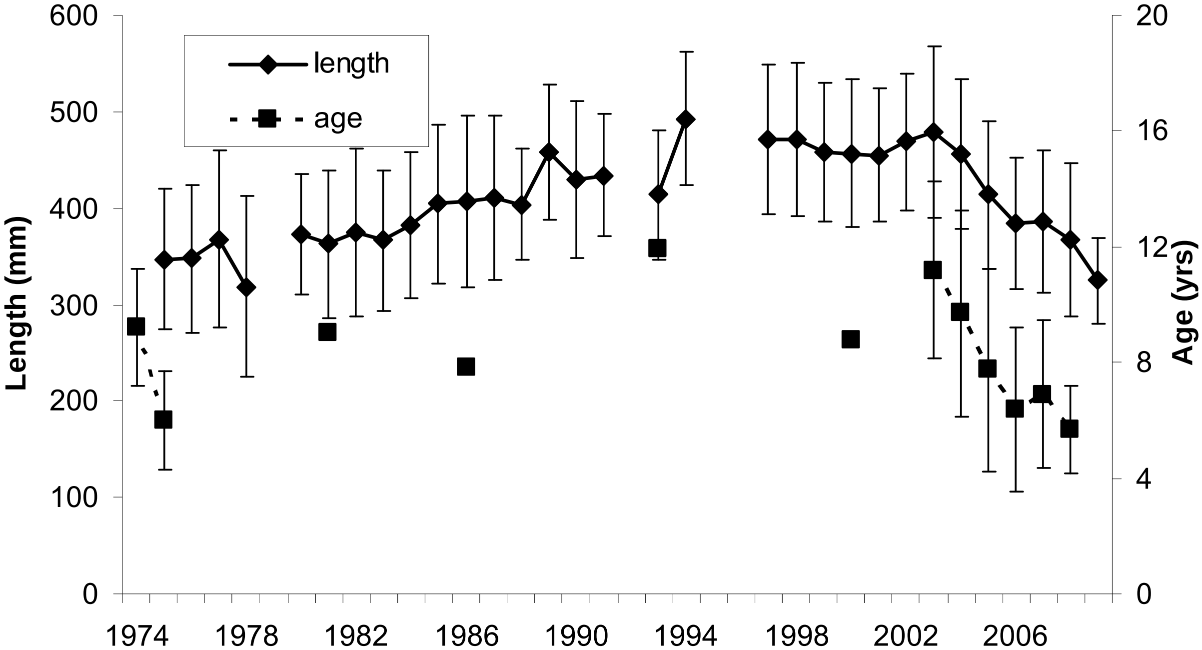

Figure 2. Mean length and age of American Eel recruits ascending Moses-Saunders generating station eel ladder on the St. Lawrence River. Error bars represent standard deviation. Data sources include Liew (1974), Casselman (2008), Greer (2008), and Ontario Ministry of Natural Resources and K. Oliveira unpubl. data.

Recruitment to the upper St. Lawrence watershed, including Lake St. Lawrence and Lake Ontario, is determined through a long-term data set from the Moses-Saunders GS eel ladder (Figure 3). The dam, which blocks upstream access with the exception of any eels that can navigate through the Snell and Eisenhower locks on the St. Lawrence Seaway, was completed in 1958. Large numbers of eels were observed accumulating at the base of the dam, and an eel ladder was installed by Ontario Power Generation and became operational on the Canadian side of the dam in 1974. In 2006, New York Power Authority installed a second eel ladder on the United States side of the generating station (NYPA 2010b).

In the past (Casselman et al. 1997), an index of the abundance of eels migrating upstream was calculated based on the daily passage during the 31-day period that represented the peak of eel migration during each year. This index was used to address variation in the operating conditions and counting strategies which varied widely over the early years of ladder operation. The total numbers of eels moving upstream at the ladder located on the Canadian side of the dam is strongly correlated (r^2=0.94) with the ladder index (Figure 4). Years with the poorest fit to this relationship (1974, 1975, 1977, 1980, and 1982) tended to be years with shorter operational periods. With the adoption of a more regular operational period and the addition of the second ladder to the Moses-Saunders GS it was decided that the total number of eels migrating upstream would be the most straightforward approach moving forward to provide an indicator of eel recruitment to the upper St. Lawrence River, and these total count data are the source used to produce Figure 3.

This long term data-set shows a catastrophic decline in eel abundance from the mid-1980s to the early 2000s, with a 97% loss of recruitment to the system (Casselman et al. 1997; Figure 3). Recruitment has been fairly stable at low levels for the past few years, with slight improvements in recruitment apparent in the most recent assessments. A variety of improvements have been made to the ladder since its inception, including recent additions of improved substrate on the ladder and the addition of an exit pipe that releases eels approximately 300 m upstream of the generating station to reduce fallback. Despite the concerns about how the addition of a second ladder at the facility and the alterations affect the comparability of the index, there can be no argument that the decline was large, and any recovery has been relatively minor.

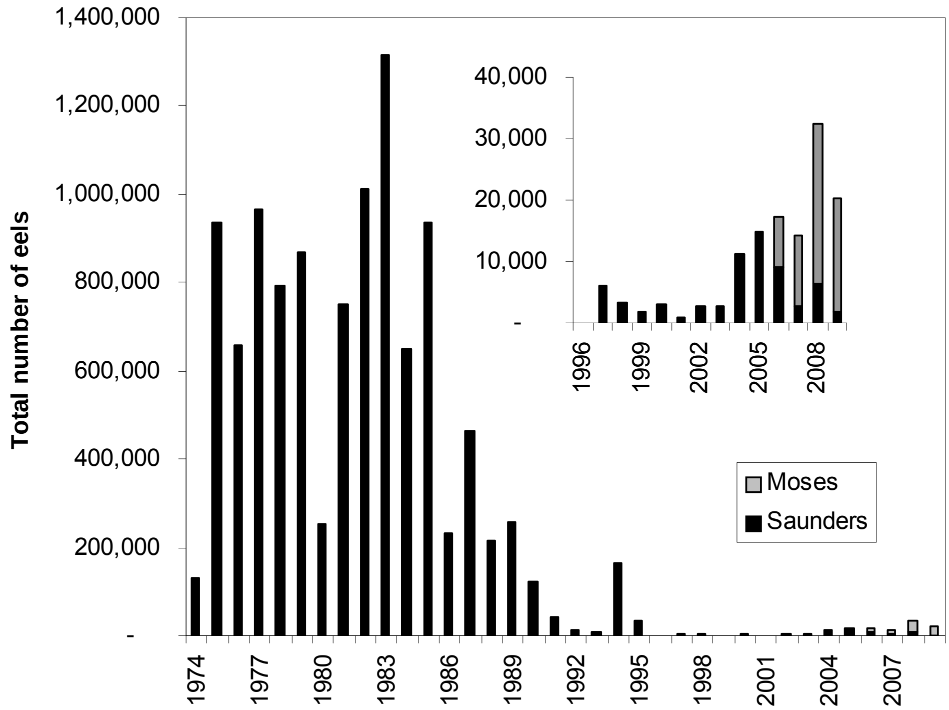

Figure 3. The Moses-Saunders generating station ladder index of American Eel recruitment to the upper St. Lawrence River. The insert shows recruitment in recent years, including the addition of a second ladder in 2006 on the Moses (United States) side of the generating station.

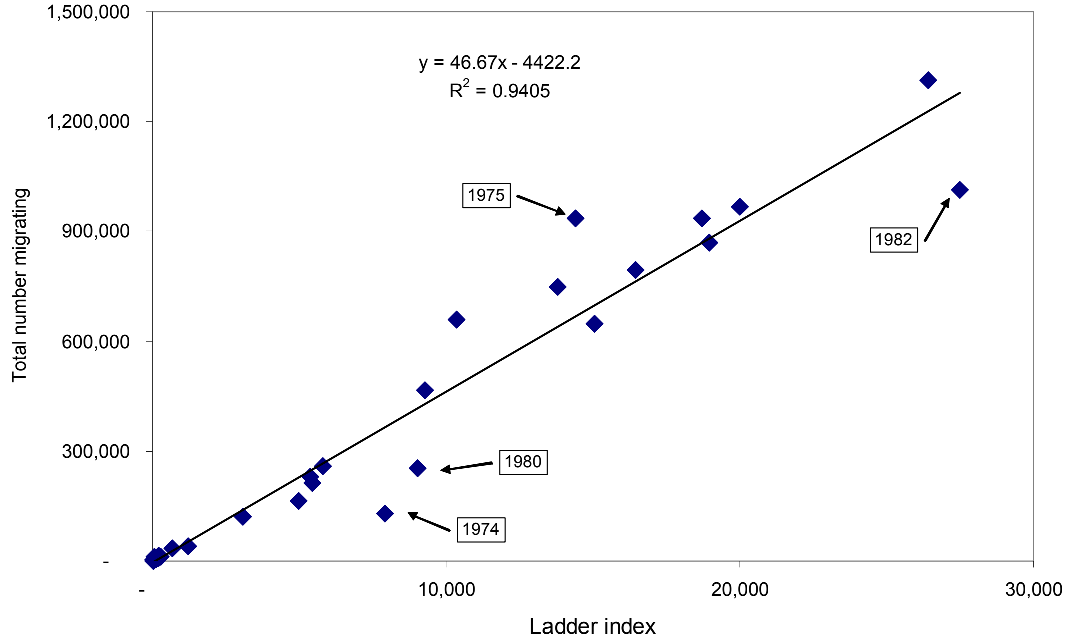

Figure 4. The relationship between the total numbers of American Eel migrating upstream at the Moses-Saunders generating station ladder and the ladder index, developed by Casselman et al. (1977), in the upper St. Lawrence River (1974 to 2005 data for the ladder on Canadian side only).

Two long-term yellow eel surveys are available from above the Moses-Saunders GS, and both show a steep decline in resident eel abundance, as one would expect given the decline in recruitment. American Eel are captured in an Ontario Ministry of Natural Resources (OMNR) Bay of Quinte fish community survey. This bottom trawl survey, conducted annually in June and July since 1972, uses a 3/4 Western bottom trawl dragged over 463 m (1/4 nautical mile). The annual catch per unit effort is averaged for five sites and across the two months. The average catch of American Eel during 1974 to 1994 was 0.94 eels per trawl, however the catch rates steadily declined to the point where no eels were captured in the 364 trawls conducted between 2003 and 2009. (Figure 5). A second yellow eel abundance index, accomplished using boat electrofishing, has been conducted in eastern Lake Ontario and the upper St. Lawrence River since 1984 (Casselman 2003). The survey captures eels over 200 m transects at depths of 2-3 m, and shows a similar decline in eel abundance to the trawl survey (Figure 5). Both indices are strongly correlated with the declining recruitment index (Casselman et al. 1997), and both surveys indicate that American Eel are at approximately 1-3% of their former abundance in eastern Lake Ontario. The best correlation (r=0.7773) between immigration up the ladder and trawl catches in the Bay of Quinte was with a 4-year lag. Electrofishing catch was best explained (r=0.8888) by the number of eels that ascended the ladder 5 years earlier.

Fully mature silver eels are not present in Ontario waters, although many downstream migrants show some characteristics of their final metamorphosis into silver eels (McGrath et al. 2003). Surveys downstream of the Moses-Saunders GS to identify dead and injured eels have been conducted since 2000, and since it has proven extremely difficult to sample out-migrating eels in the St. Lawrence River (McGrath et al. 2003), it provides an important index of outmigrating eels from this system. The tailrace survey is conducted in a systematic manner each year, sampling twice per week from mid- June through very early October. The numbers of these eels has declined by approximately 20% annually since the start of the survey in 2000 (NYPA 2010b; Figure 6). Allowing for a 10- to 15-year yellow eel growth phase in the upper St. Lawrence and Lake Ontario (Casselman 2003), this decrease in number of downstream migrants is consistent with the decline observed in upstream juvenile migrants beginning in the mid-1980s. The best correlation (r= 0.8651) between the abundance of upstream migrants and the numbers of eels observed in the GS tailwaters is with an 18-year lag. The success of the tailrace survey on the St. Lawrence River has resulted in a similar protocol being established at other generation stations in the Ottawa River watershed (Thompson et al. 2010).

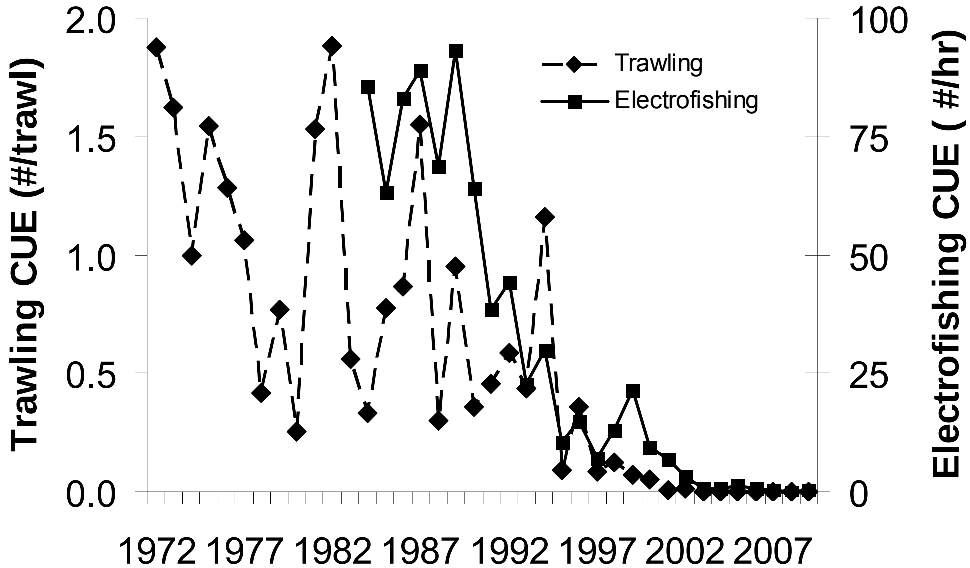

Figure 5. Resident American Eel abundance indices for trawling in the Bay of Quinte (diamonds) and boat electrofishing in eastern Ontario (squares).

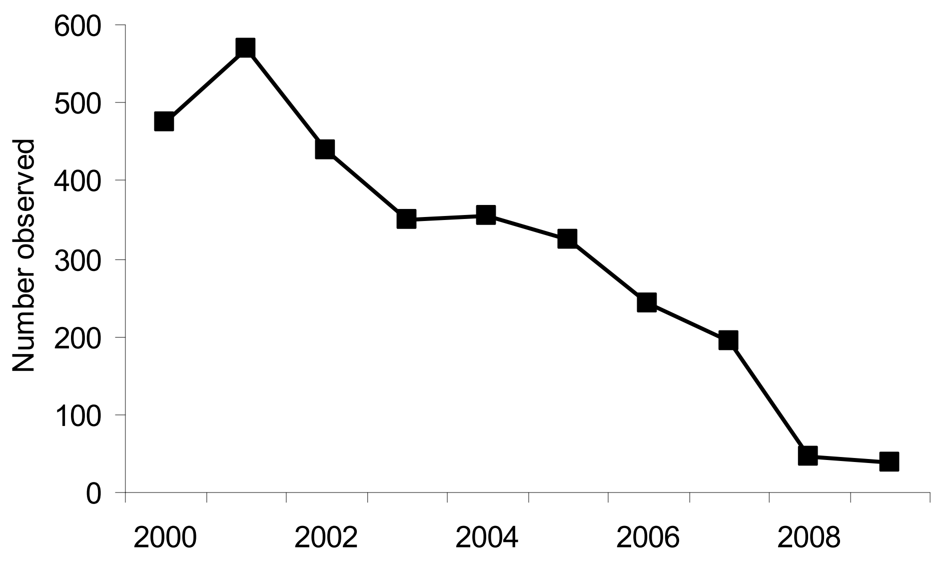

Figure 6. Counts of out-migrating American Eel carcasses detected downstream of the Moses-Saunders GS (NYPA 2010).

Trap net data Ottawa River watershed from 1961-2000 show a steep decline in abundance past the second barrier on the system (MacGregor et al. 2009). A 2009 electrofishing survey found low densities, 3.6 eel/ha, below the Carillon Dam, the first barrier on the Ottawa River. Even lower densities were observed above the dam, ranging from 0.2 to 1.2 eels/ha, depending on the river segment surveyed (Casselman and Marcogliese 2010a). Historically, Aboriginal Traditional Knowledge (ATK) and commercial harvest records indicate that eel numbers were substantial, but have been very low since the 1950s, particularly in the upper reaches (MacGregor et al. 2009). Quebec commercial eel harvests from the Ottawa River ranged from 3.4 -15.0 m.t. annually between 1930 and 1937 (Dymond 1939). Commercial harvest records for the North Bay MNR District waters of the Ottawa River show thousands of pounds of eels harvested during the period 1924-1938, peaking at 4,027 kg in 1932 (OMNR 1984).

An American Eel conservation stocking experiment was initiated by Ontario Power Generation, in collaboration with OMNR and Fisheries and Oceans Canada in 2006. To date, some 4 millions glass eels have been stocked into the upper St. Lawrence River (Mallorytown Landing) and Lake Ontario (Bay of Quinte; Table 2). All stocked eels were marked with a fluorescent dye to distinguish them from naturally migrating eels. Stocking was conducted to supplement recruitment of eels to the Upper St. Lawrence River and Lake Ontario until the number of wild eels climbing the ladders recovers. In addition, these fish will also provide a stock to allow for future studies. The stocking program will complicate estimation of the abundance of natural migrants into the Lake Ontario system in the future.

Table 2. American Eel stocking rates, dates of stocking, and stocking locations by year, along with the mean length and mass of stocked American Eel for each stocking event. The numbers in parentheses indicate the sample size and the standard error. Blank cells indicate no data were taken. Data for 2010 should be considered preliminary.

Stocking Date	Location	Number stocked	Mean length (mm)	Mean mass (g)
October 12, 2006	Mallorytown Landing	167,000		0.60 (n = 25; ±0.004)
June 5, 2007	Mallorytown Landing	294,000	59.2 (n=49; ±0.5)	
May 15, 2008	Mallorytown Landing	797,000	60.9 (n=40; ±0.6)	0.17 (n=40; ±0.0006)
May 29, 2008	Mallorytown Landing	518,000	60.4 (n=40; ±0.5)	0.14 (n=40; ±0.0004)
June 11, 2008	Bay of Quinte at Deseronto	686,000	56.5 (n=40; ±0.5)	0.14 (n=40; ±0.006)
June 2, 2009	Mallorytown Landing	650,000	59.1 (n=246; ±0.4)	0.18 (n=246; ±0.04)
June 2, 2009	Bay of Quinte at Deseronto	650,000		
June 21, 2010	Mallorytown Landing	74,916	57.0 (n=101; ±0.4)	0.14 (n=101; ±0.05)
June 21, 2010	Bay of Quinte at Hay Bay	67,117		

No estimates of survival are available, but stocked eels have dispersed throughout the Canadian waters of Lake Ontario, and they have achieved reasonably high densities in the main stocking locations. Stocked American Eels have been captured as far east as the town of Brockville on the St. Lawrence River, and as far west as the Credit River in Mississauga. The stockings have been assessed by boat electrofishing, and densities continue to increase as further eels are stocked (Table 3). Higher fall densities are expected over spring densities from the same year with the addition of each new cohort.

Table 3. The total number of eels caught and observed, along with mean density estimates, in the first year of an American Eel conservation stocking effectiveness monitoring program. Data were collected from two main stocking locations in the spring and fall of 2009, and the spring of 2010. The numbers in brackets represent ± standard error.

Location	Sampling period	Mean number per transect	Density (# / ha)
Mallorytown Landing	Spring 2009	0.64 (0.19)	25.7
	Fall 2009	1.36 (0.38)	54.2
	Spring 2010	1.32 (0.31)	53.1
Bay of Quinte	Spring 2009	0.75 (0.19)	30.0
	Fall 2009	6.82 (1.04)	272.9
	Spring 2010	2.72 (0.38)	109.0

b) Identify threats to abundance

There is no single, identifiable cause for the near extirpation of American Eel from Ontario, and it is likely that the cumulative effect of a number of threats aided in the decline. Threats that occur outside of Ontario must be as thoroughly considered as threats from within the Province though, given the inter-jurisdictional nature of the American Eel life cycle. Potential threats include harvesting, loss of habitat access, habitat alteration, productivity and food web alterations, turbine mortality, parasites, and toxins and contaminants. Each threat is discussed more thoroughly in a threats section below.

c) Abundance trend and signs of recovery

The average numbers of American Eel ascending the ladders at the Moses-Saunders have been increasing somewhat in the past few years (Figure 3). Mean size and age of these eels has also decreased (Figure 2), which is viewed as another positive sign. However, the average abundance for the 2000s (11,949 eels per year) is only 2% of the numbers observed in the 1980s (608,044 eels per year) and 1994 (163,518 eels) was the last year of sizeable movement of eels up the ladders. In addition, abundance of larger eels in the trawling, electrofishing and tailwater surveys is not increasing, and abundance levels are still at <5% of their historic levels. Given that increases in Ontario are likely dependent on large, density-dependent recruitment events from American Eels produced in jurisdictions outside of the Province (Casselman 2003), and long-term abundance trends elsewhere are not known, it is likely that recovery in Ontario will be at best protracted.

4) CHARACTERISTICS OF AND THREATS TO AMERICAN EEL HABITAT IN ONTARIO

The American Eel once exhibited the largest range of any freshwater fish species in the western hemisphere, and held a dominant position in the fish communities by numbers and biomass in many habitats (Smith and Saunders 1955, Ogden 1970). Their historic range included all accessible freshwater, estuarine and coastal marine waters of the western North Atlantic from Venezuela in the south through the Gulf of Mexico to Labrador in the north and as far inland as the headwaters of the Mississippi River (U.S.) and, in Ontario, Niagara Falls and the headwaters of the Ottawa River.

Ontario provided what is believed to be crucial rearing habitat for the largest, most fecund female yellow eels (COSEWIC 2006, Tremblay 2009). While both the marine and freshwater contingents are important to the conservation of American Eel, especially severe anthropogenic challenges faced by the species occur principally in freshwater habitats. Losses in the freshwater contingent are especially concerning as large females are primarily produced in these habitats. American Eel in Ontario has undergone a significant range contraction due to barriers (Figure 7), as formerly available habitats are no longer accessible. Estimates from the Ottawa River watershed of losses of 3,700 km^2 of suitable habitat and the lost production of approximately 255,000 silver eels per year (Quebec and Ontario combined) before extensive dam construction provide an idea of valuable these habitats were (Verreault et al. 2004).

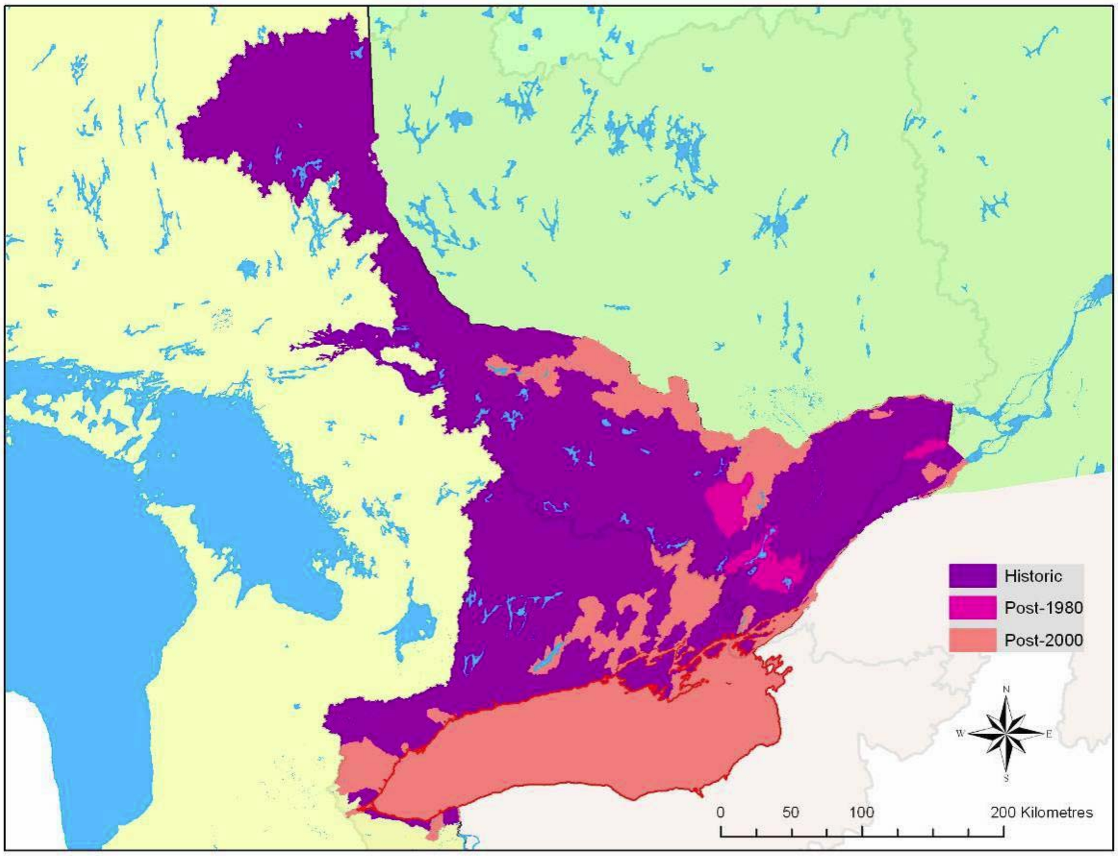

Figure 7. The geographic extent of the American Eel in Ontario from MacGregor et al. (2010). Information used to depict the distribution of American Eel in Ontario was compiled by the American Eel Recovery Team from Aboriginal traditional knowledge, local community knowledge, archaeological data and recorded captures via netting.

The listing of American Eel as Endangered under Ontario's *Endangered Species Act* (2007) will provide additional habitat protection for the species in Ontario. The draft Provincial recovery strategy focuses recovery efforts on restoring access to and safe downstream passage from historic watersheds (MacGregor et al. 2010).

5. RESIDENCE

The SARA definition of residence is not applicable to any aspect of the American Eel life cycle.

6. THREATS

American Eel face a myriad of anthropogenic threats across their wide distribution. Because it is hypothesized that the dispersal of young eels from the Sargasso Sea is driven by large pulses of young eels (Casselman 2003), recovery of abundance and distribution within the distant waters of Ontario will depend significantly on improved production and enhanced density-dependent dispersal of recruits from the Sargasso Sea. This in turn is driven by the numbers of mature eels that return to safely to the Sargasso Sea to spawn. Therefore threats that occur outside of Ontario are as important as threats from within the Province. Potential threats include harvesting, loss of habitat access, habitat alteration, productivity and food webs alterations, turbine mortality, parasites, and toxins and contaminants. Analysis by de Lafontaine et al. (2009) showed that the onset of the silver eel decline preceded the major decline in recruitment in the mid-1980s, suggesting that the decline in spawning stock size was not due to poor recruitment but rather to large-scale mortality factors associated with high exploitation in upstream Lake Ontario and to the construction of hydropower dams in the late 1950s.

HARVEST

All continental life stages of American Eel are harvested throughout their range, and there has been no coordinated attempt to establish range wide limits that would be sustainable at the population level (MacGregor et al. 2008). The Province of Ontario has commercial harvest records that cover more than a century for the upper St. Lawrence River and Lake Ontario. In the 1960s and 1970s, interest in commercial eel harvest increased coincident with declines in other commercially important species (Christie 1973, Hurley 1973). In the 1970s, reported eel harvest increased rapidly in response to new markets, rising prices, and an abundance of eels (Christie et al. 1987, Casselman et al. 1997, MacGregor et al. 2008). Reported annual harvest peaked at over 200 metric tons in the late 1970s, with a landed value of U.S. $574,000. In 1982/83, European markets for Lake Ontario eels were closed due to contaminant levels, resulting in a dramatic short-term decline in harvest. Between 1984 and 1993, reported annual harvest ranged from 104 to 124 metric tons. Since 1993, eel harvests declined precipitously in all areas above the Moses-Saunders Power Dam in spite of an increase in price (Mathers and Stewart 2007). The observed declines in abundance in Ontario occurred just after the period of peak harvests. The commercial yellow eel fishery was closed in Ontario in 2004, and a small recreational fishery was closed in 2005. Yellow and silver eels continue to be harvested in the St. Lawrence River system, and glass, yellow, and silver eels are harvested by fishers in eastern Canada and the United States.

HABITAT ACCESS

It has been estimated that 85% of the freshwater habitat for migratory fish in the United States has been lost due to barriers (Lary et al. 1998). This value is in agreement with an estimate that American Eels may have been eliminated from 81 per cent of their historic habitat from Connecticut to Maine due to the construction of barriers in their watersheds (ASMFC 2000). The situation appears similar in Ontario where at least 953 dams exist within the American Eel's historical range (MacGregor et al. 2010). With the exception of the ladders at the Moses-Saunders GS, no provisions for upstream passage have been made at any of Ontario's 86 other hydroelectric facilities within the historical range of the American Eel, and few other barriers provide passage. Casselman and Marcogliese (2010a) found a disproportionately high abundance of eels immediately below Moses-Saunders GS, and two barriers on the Ottawa River, the Carillion and Chats GSs, which suggests that effective passage continues to be a problem in Ontario, even where ladders exist. Clearly, the numerous barriers within the historical provincial range of American Eels will have significantly limited production from large areas of formerly important eel-producing watersheds. In particular, generating stations provide the most formidable challenge due to their height (MacGregor et al. 2010). Interestingly, there are recent reports of small stocked eels penetrating far into watersheds where they have been absent for many decades likely due to the better migratory abilities of glass eels (Scott Reid, OMNR species-at-risk scientist, pers. comm.).

Within the historic range of eels in Ontario, barriers have led to substantial cumulative loss in access to formerly productive maturing habitat, and reduction of Ontario's production of its large, highly fecund females. Range contraction has been clearly documented within the Ottawa River (MacGregor et al. 2009), where an estimated 3,700 km^2 of suitable habitat (Quebec and Ontario combined) was present before extensive dam construction throughout the watershed (Verreault et al. 2004). This equated to an estimate of lost production of approximately 255,000 silver eels per year (Verreault et al. 2004).

HABITAT, PRODUCTIVITY AND FOOD-WEB CHANGES

Portions of the remaining accessible habitat may be degraded due to poor land use practices, particularly timber harvest, farming practices and urbanization of watersheds that impair stream quality and riparian zones, posing additional potential stressors to yellow eels (Machut et al. 2007). The invasion of dreissenid mussels (e.g., zebra mussel; *Dreissena polymorpha*) may also have had some impact on eels in some waters (e.g., Lake Ontario), increasing water clarity and forcing eels into deeper and thermally less preferred waters (J. Casselman, unpubl. data). Productivity changes, such as phosphorus reduction and fish-community changes such as alewife reduction and the emergence of gobies as the dominant benthic fish species may also affect eel production in the Lake Ontario - St. Lawrence River system. Any direct impacts of habitat, productivity and food-web alterations on American Eel in Ontario remain speculative, however.

TURBINE MORTALITY

Like elsewhere in the world, hydroelectric facilities in Ontario pose significant challenges to eels as they impart serious individual and cumulative mortalities at the watershed level to downstream migrants en route to spawn (McCleave 2001, MacGregor et al. 2009, MacGregor et al. 2010). There are 87 hydroelectric facilities within the historic range of eels in Ontario, and these facilities continue to cause mortality where eels still reside. When the American Eel was still abundant in North American watersheds, entanglement in turbines were sufficient to cause major operational difficulties or complete shutdowns of power plants and mills, and these mortalities have been ongoing for the past century at many facilities (MacGregor et al. 2009).

Cumulative mortalities of eels passing through a series of hydroelectric facilities on smaller watersheds can also be very high, at times approaching 100%. For instance, Donnil et al. (2001: in ICES 2003) estimated an average annual mortality of 92.7% for European eel (*A. anguilla*) in the River Rhine for a succession of 12 hydroelectric facilities. This suggests that cumulative turbine mortalities imposed by a series of facilities on the Trent and Ottawa Rivers (MacGregor et al. 2009) are also likely very high. Since the closure of commercial and sport fisheries in Ontario in 2004 and 2005 respectively, turbines are the greatest anthropogenic source of eel mortality in the province.

PARASITES

The most significant health concern facing eel populations worldwide is currently the invasive swim bladder nematode *Anguillicoloides crassus*. Originally endemic to eastern parts of Asia as a parasite of *Anguilla japonica*, it was accidentally introduced to Europe through commercial trade roughly 30 years ago (Knopf 2006). After its release *A. crassus* invaded nearly all

European waters in less than a decade, with European eels in some areas approaching nearly 100% infection rate (Kennedy and Fitch 1990). In 1995, the presence of *A. crassus* was confirmed at a Texas aquaculture facility (Fries et al. 1996) and has since been confirmed along the eastern coast of the United States, with prevalence reported as high as 76% in some southern New England watersheds (GMCME 2007). The first Canadian occurrences of this parasite have recently been confirmed in New Brunswick and Nova Scotia (Rockwell et al. 2009, Aieta and Oliveira 2009). The parasite has been implicated in the decline of eels species around the world because it can have devastating effects on eels, including an enlarged abdomen, thickening of the swim bladder wall, swim bladed collapse, dilation of blood vessels, hemorrhagic lesions, secondary bacterial infections, decreased swim speed, decreased swimming endurance and ultimately death (Haenen et al. 1989, Banning and Haenen 1990, Sprengel and Lüchtenberg 1991, Palstra et al., 2007, Sjoberg et al. 2009). There is no evidence of the parasite in Ontario waters to date, but if it is harming American Eels from a large part of the species range it could be a contributor to the declines in American Eel observed in Ontario.

It is apparent that *A. crassus* is spread via human pathways given its jump across continents and its non-contiguous distribution. Glass eels stocked into Ontario waters through the conservation stocking experiment convey a risk of transfer into the Province, despite the extensive health screening that occurs prior to release.

TOXINS AND CONTAMINANTS

Concerns about high contaminant burdens influencing reproductive success, leading to population declines, are particularly well-documented for the *A. anguilla* (Geeraerts and Belpaire 2010). A wide variety of chemicals may affect eel fertility, survival, and migration success. The importance of contaminants has not been quantified in American Eel despite the fact that contaminants in eels in the St. Lawrence River system have elevated levels of many contaminants (Reid and Meisenheimer 2001).

SUMMARY

American Eel once comprised an important component of the fish community, and supported significant commercial fisheries, in the Ottawa River and Lake Ontario / upper St. Lawrence River watersheds in the Province of Ontario. These eels were large, fecund females, and it is estimated that eels from these watersheds comprised over 50% of the potential fecundity from Canadian waters. Today, eel recruitment to Ontario waters has declined by approximately 97% since the early 1980s. A slight rebound in recruitment is apparent since 2004. Two fisheries-independent yellow eel abundance indices show similar declines over the same timeframe, and the species is now listed as Endangered under the province's *Endangered Species Act* (2007). Restrictions to rearing habitat access have resulted in significant lost production potential, estimated to be over 250,000 silver eels from the Ottawa River watershed alone. Recovery of abundance and distribution within the waters of Ontario will depend on improved production and enhanced density-dependent dispersal of recruits from the Sargasso Sea. Therefore, threats that occur outside of Ontario are as important as threats from within the province. Potential threats include harvesting, loss of habitat access, habitat alteration, productivity and food webs alterations, turbine mortality, parasites, and toxins and contaminants.

ACKNOWLEDGEMENTS

We thank A. Bendig, R. Macgregor, G. Pope and D. Stanley for comments that greatly improved this manuscript. This manuscript relied heavily on work produced by R. Macgregor, J. Casselman, L. Grieg, R. Threader, D. Stanley, and G. Pope.

REFERENCES

Aieta A.E and K. Oliveira. 2009. Distribution, prevalence, and intensity of the swim bladder parasite Anguillicola crassus in New England and eastern Canada. Diseases of Aquatic Organisms 84: 229-35.

ASMFC (Atlantic States Marine Fisheries Commission). 2000. Interstate Management Plan for American Eel. Report No. 36:1-93.

Avise J.C. 2003. Catadromous eels of the North Atlantic: a review of molecular genetic findings relevant to natural history, population structure, speciation, and phylogeny. *In* Eel Biology. *Edited by* K. Aida et al., Springer-Verlag, Tokyo. p. 31-48.

Banning, P. and O.L.M. Haenen. 1990. Effects of the swimbladder nematode *Anguillicola crassus* in wild and farmed eel *Anguilla anguilla. In* Pathology in Marine Science. *Edited by* Perkins, F. O. and T.C. Cheng. Academic Press New York, NY p. 317-330.

Casselman, J.M. 2003. Dynamics of resources of the American Eel, Anguilla rostrata: declining abundance in the 1990s. *In* Eel Biology. *Edited by* K. Aida et al. Springer-Verlag, Tokyo. p. 255-274.

Casselman, J.M. 2008. Otolith age interpretations of juvenile American Eels ascending the R.H. Saunders Eel Ladder, Moses-Saunders Generating Station, upper St. Lawrence River, 2003-2007. Conducted by AFishESci Inc. for Ontario Power Generation through the Species at Risk Stewardship Program. 13 p. + 5 appendices.

Casselman, J.M. and L.A. Marcogliese. 2010b. Abundance and distribution of American Eels (*Anguilla rostrata*) and other fish in the Ontario waters of the Upper St. Lawrence River and Charleston Lake, Gananoque River system, 2009, as determined by quantitative electrofishing. Conducted by AFishESci Inc. in cooperation with Plenty Canada and Mississippi Valley Conservation for, and with financial support provided by Ontario Species at Risk Stewarship Fund. March 2010. 41 pages + 4 appendices (total 247 pages).

Casselman, J.M. and L.A. Marcogliese. 2010a. Abundance and Distribution of American Eels (*Anguilla rostrata*) and other fish in the Lower Mississippi and Ottawa Rivers, 2009, as Determined by Quantitative Electrofishing. Conducted by AFishESci Inc. in cooperation with Plenty Canada and Mississippi Valley Conservation for, and with financial support provided by Ontario Species at Risk Stewardship Fund.

Casselman, J.M., L.A. Marcogliese and P.V. Hodson. 1997. Recruitment index for the upper St. Lawrence River and Lake Ontario eel stock: a re-examination of eel passage at the R.H. Saunders hydroelectric generating station at Cornwall, Ontario, 1974-1995. *In* The

American Eel in eastern Canada: Stock status and management strategies. Proceedings of Eel Management Wrokshop, January 13-14, 1997, Quebec City, QC. *Edited by* R.H. Peterson. Can. Tech. Rep. Fish. Aquat. Sci. 2196. p. 161-169.

Christie, W.J. 1973. A review of the changes in the fish species composition of Lake Ontario. Great Lakes Fisheries Commission Technical Report 23: 65 p.

Christie, W.J., K.A. Scott, P.G. Sly and R.H. Strus. 1987. Recent changes in the aquatic food web of eastern Lake Ontario. Can. J. Fish. Aquat. Sci. 44 (Suppl. 2): 37-52.

COSEWIC 2006. COSEWIC assessment and status report on the American Eel *Anguilla rostrata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 71 p. Available: http://dsp-psd.pwgsc.gc.ca/Collection/CW69-14-458-2006E.pdf

Côté, C.L., M. Castonguay, G. Verreault and L. Bernatchez. 2009. Differential effects of origin and salinity rearing conditions on growth of glass eels of the American Eel *Anguilla rostrata*: implications for stocking programmes. Journal of Fish Biology 74, 1934-1948.

de Lafontaine, Y., P. Gagnon and B. Cote. 2009. Abundance and individual size of American Eel (*Anguilla rostrata*) in the St. Lawrence River over the past four decades. Hydrobiologia. DOI 10.1007/s10750-009-9850-5. 14 p.

Dekker, W., J.M. Casselman, D.K. Cairns, K. Tsukamoto, D. Jellyman, H. Lickers. 2003. Worldwide decline of eel resources necessitates immediate action. Quebec Declaration of Concern. Fisheries 28: 28-30.

Donnil, W., K-J. Maier and H. Vicenti. 2001. Bestandsentwicklung des Aals (*Anguilla anguilla*) im Hochrhein. Mitteilung Zur Fischeri, BUWAL, Bern, Germany. du Creux, F. 1664.

Dymond, J. R. 1939. The fishes of the Ottawa region. Contributions of the Royal Ontario Museum of Zoology 15, Toronto, Ontario.

Fries, L.T. and D.J. Williams. 1996. Occurrence of *Anguillicola crassus*, an exotic parasitic swim bladder nematode of eels, in the southeastern United States. Transactions of the American Fisheries Society 125: 794-797.

Geeraerts, C. and C. Belpaire. 2010. The effects of contaminants in European eel: a review. Ecotoxicology 19:239–266.

Greer, C. 2008. Long-term changes in the population structure of juvenile American Eels, *Anguilla rostrata*, in the upper St. Lawrence River, with reference to age, growth, body condition, and thermal history. Thesis (Honours) Queens University, Kingston. 53 p.

GMCME (Gulf of Maine Council on the Marine Environment). 2007. American Eels: restoring a vanishing resource in the Gulf of Maine. Available: http://www.wildlife.state.nh.us/marine/marine_PDFs/American_Eels_GulfOfMaine.pdf 12 p.

Haenen, O.L.M., L. Grisez, D. de Charleroy, C. Belpaire and F. Ollevier. 1989. Experimentally induced infections of European eel *Anguilla anguilla* with *Anguillicola crassus* (Nematoda, Dracunculoidea) and subsequent migration of larvae. Diseases of Aquatic Organisms 7, 97–101.

Helfman, G.S., D.E. Facey, L.S. Hales, Jr. and E.L Bozeman, Jr. 1987. Reproductive ecology of the American Eel. *In* Common strategies of anadromous and catadromous fishes. *Edited by* M.J. Dadswell, R.L. Klauda, C.M. Moffitt, R.L. Saunders, R.A. Rulifson and J.E. Cooper. American Fisheries Society Symposium 1, Maryland. p 42-56.

Hurley, D.A. 1972. The American Eel (*Anguilla rostrata*) in eastern Lake Ontario. Journal of the Fisheries Research Board of Canada 29: 535-543.

Hurley, D.A. 1973. The commercial fishery for American Eel *Anguilla rostrata* (Lesueur) in Lake Ontario. Transactions of the American Fisheries Society 102: 369-377.

Jessop, B.M., J.C. Shiao, Y. Iizuka and W.N. Tzeng. 2002. Migratory behaviour and habitat use by American Eels *Anguilla rostrata* as revealed by otolith microchemistry. Marine Ecology Progress Series 233: 217-229.

Kennedy, C.R. and D.J. Fitch. 1990. Colonization, larval survival and epidemiology of the nematode *Anguillicola crassus*, parasitic in the eel, *Anguilla anguilla*, in Britain. - Journal of Fish Biology 36: 117-131.

Knopf, K. 2006. The swimbladder nematode *Anguillicola cra*ssus in the European eel *Anguilla anguilla* and the Japanese eel *Anguilla japonica*: differences in susceptibility and immunity between a recently colonized host and the original host. Journal of Helminthology. 80:129-136.

Lary, S.J., W.-D. Busch, C.M. Castigione and R. MacDonald. 1998. Distribution and availability of Atlantic Coast freshwater habitats for American Eel (*Anguilla rostrata*). U.S. Fish and Wildlife Service, Draft Administrative Report: 98-02

Liew, P.K. 1974. Age determination of American Eels based on structure of their otoliths. Pages 124-136 in T.B. Bagenal, editor. Ageing of Fish. Proceedings of an International Symposium. Unwin Brothers Limited, Surrey, UK.

MacGregor, R.B., A. Mathers, P. Thompson, J.M. Casselman, J.M. Dettmers, S. LaPan, T.C. Pratt and W.A. Allen. 2008. Declines of American Eel in North America: Complexities associated with bi-national management. *In* International governance of fisheries ecosystems: learning from the past, finding solutions for the future. *Edited by* M.G. Schechter, W.W. Taylor and N.J. Leonard. American Fisheries Society, Bethesda, MD. p. 357-381.

MacGregor, R.B., J.M. Casselman, W.A. Allen, T.Haxton, J.M. Dettmers, A. Mathers, S. LaPan, T.C. Pratt, P. Thompson, M. Stanfield, L. Marcogliese , J-D. Dutil. 2009. Natural heritage, anthropogenic impacts and bio-political issues related to the status and sustainable management of American Eel: A retrospective analysis and management perspective at the population level. *In* Challenges for Diadromous Fishes in a Dynamic Global Environment. *Edited by* Haro, A.J., K.L. Smith, R.A. Rulifson, C.M. Moffitt, R.J. Klauda, M.J. Dadswell, R.A. Cunjak, J.E. Cooper, K.L. Beal and T.S. Avery. American Fisheries Symposium 69, Bethesda, MD. p. 713-739.

MacGregor, R., J. Casselman, L. Greig, W.A. Allen, L. McDermott and T. Haxton. 2010. DRAFT (August 6, 2010) Recovery Strategy for the American Eel (*Anguilla rostrata*) in Ontario. Ontario Recovery Strategy Series. Prepared for Ontario Ministry of Natural Resources, Peterborough, Ontario. 67 p.

Machut, L.S., K.E. Limburg, R.E. Schmidt and D. Dittman. 2007. Anthropogenic impacts on American Eel demographics in Hudson River tributaries, New York. Transactions of the American Fisheries Society 136: 1699-1713.

Mathers, A. and T.J. Stewart. 2007. Management of American Eels in Lake Ontario and the Upper St. Lawrence River. *In* Eels at the edge. *Edited by* J.M. Casselman and D.K. Cairns. American Fisheries Society, Symposium 58, Bethesda, Maryland. p. 359-366

McCleave, J.D. 2001. Simulation of the impact of dams fishing weirs on the reproductive potential of silver-phase American Eels in the Kennebec River basin. North American Journal of Fisheries Management 21: 592-605.

McGrath, K.J., J. Dembeck, J.B. McLaren, A. Fairbanks, K. Reid and S.J. Cluett. 2003. Surface and midwater trawling for American Eels in the St. Lawrence River. *In* Biology, Management and Protection of Catadromous Eels. *Edited by* D. Dixon. American Fisheries Society, Symposium 33, Bethesda, Maryland. p. 307–313.

NYPA (New York Power Authority). 1998. Estimation of survival of American Eel after passage through a turbine at the St. Lawrence-FDR Power Project, New York: Draft Final Report. Prepared by Normandeau Associates Inc. and J.R. Skalski.

NYPA (New York Power Authority). 2010a. Operation and monitoring of the eel passage facility at the Robert Moses Power Dam in 2009 – Final Report. Prepared by Milieu inc., LaPrairie Quebec, for NYPA, White Plains, NY.

NYPA (New York Power Authority). 2010b. 2009 Survey of American Eel in the tailwater of the International St. Lawrence Power Project - Final Report. Prepared by Riveredge Associates

Oliveira, K. and J.D. McCleave. 2002. Sexually different growth histories of the American Eel in four rivers in Maine. Transactions of the American Fisheries Society 131: 203-211.

Ogden, J.C. 1970. Relative abundance, food habits, and age of the American Eel, *Anguilla rostrata*, in certain New Jersey streams. Transactions of the American Fisheries Society 99: 54-59.

OMNR (Ontario Ministry of Natural Resources). 1984. Commercial fish production historic records, Northern Inland Waters 1924-1982. Written correspondence from K.J. Chambers to the Regional Directors North Central Region, Northern Region and Northeastern Region, Ontario Ministry of Natural Resources.

Palstra, A. P., D.F.M. Heppener, V.J.T. van Ginneken, C. Szekely and G. van den Thillart. 2007. Swimming performance of silver eels is severely impaired by the swim-bladder parasite *Anguillicola crassus*. Journal of Experimental Marine Biology and Ecology 352**:** 244-256.

Reid, K.B. and P. Meisenheimer. 2001. The decline of American Eel (*Anguilla rostrata*) in the Lake Ontario/St. Lawrence Ecosystem: A modelling approach to identification of data gaps and research priorities. Report Prepared for lake Ontario Technical Committee by Beak International Incorporated, ref.: 21852.10. Available: http://www.glfc.org/lakecom/loc/eel.pdf

Rockwell, L.S., K.M.M. Jones and D.K. Cone. 2009. First Record of *Anguillicoloides crassus* (Nematoda) in American Eels *(Anguilla rostrata)* in Canadian Estuaries, Cape Breton, Nova Scotia. Journal of Parasitology, 95: 483-486.

Smith, M.W. and J.W. Saunders. 1955. The American Eel in certain freshwaters of the Maritime Provinces of Canada. Journal of the Fisheries Research Board of Canada. 12: 238-269.

Sjoberg, N. B., E. Petersson H. Wickstrom and S. Hansson. 2009. Effects of the swimbladder parasite *Anguillicola crassus* on the migration of European silver eels *Anguilla anguilla* in the Baltic Sea. Journal of Fish Biology 74: 2158-2170.

Sprengel, G. and H. Lűchtenberg. 1991. Infection by endoparasites reduces maximum swimming speed of European smelt *Osmerus eperlanus* and European eel *Anguilla anguilla*. Diseases of Aquatic Organisms. 11: 31-35.

Tesch, F.-W. 2003. The eel. Blackwell Science, Oxford, U.K.

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

Thompson, E., J. Zadow and J. McCann. 2010. American Eel hydro dam tail waters monitoring project 2009: assessment of mortalities on the Ottawa and Mississippi Rivers. Report prepared for Community Stewardship Council of Lanark County. Box 37, Perth, Ontario.

Tremblay, V. 2009. Reproductive strategy of female American Eels among five subpopulations in the St. Lawrence River watershed. *In*. Eels at the edge Edited by J.M. Casselman and D.K. Cairns. American Fisheries Society, Symposium 58, Bethesda, Maryland. p. 85-102.

Vélez-Espino, L.A. and M.A. Koops. 2009. A synthesis of the ecological processes influencing variation in life history and movement patterns of American Eel: towards a global assessment. Reviews in Fish Biology and Fisheries. 20: 163-186.

Verreault, G. and P. Dumont. 2003. An estimation of American Eel escapement from the upper St. Lawrence River and Lake Ontario in 1996 and 1997. *In* Biology, Management and Protection of Catadromous Eels. *Edited by* D. Dixon. American Fisheries Society, Symposium 33, Bethesda, Maryland. p. 243–251.

Verreault, G., P. Dumont and Y. Mailhot. 2004. Habitat losses and anthropogenic barriers as a cause of population decline for American Eel (*Anguilla rostrata*) in the St. Lawrence watershed, Canada. International Council for the Exploration of the Sea. CM Document 2004/S:04, Copenhagen, Denmark. 12p. Available: http://www.ices.dk/products/CMdocs/2004/S/S0404.pdf