STATUS OF AMERICAN EEL AND PROGRESS ON ACHIEVING MANAGEMENT GOALS

Illustration by Jeffrey G. Domm

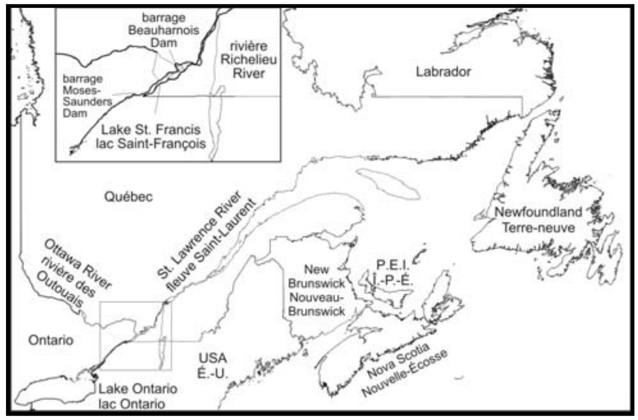

Figure 1. *Provinces of Canada in which American Eel is found. Inset shows specific locations in the Lake Ontario – upper St. Lawrence River area.*

Context

In 2006, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed American Eel in Canada as "Special Concern". An American Eel Management Plan for Canada has been drafted and components of the draft management plan are being delivered by the appropriate Fisheries and Oceans (DFO) administrative regions and by the provinces of Quebec and Ontario. Management agencies and stakeholders have initiated a number of measures to address threats to American Eel. The draft management plan is intended to meet the requirements for a species listed as "Special Concern" under the federal government's Species at Risk Act *although at the time of writing, no decision has been made on whether or not to list American Eel.*

A request for scientific advice was submitted by DFO's Ecosystems and Fisheries Management Branch (DFO EFM) to consider the following questions:

1. *What is the current status of American Eel in Canada?*
2. *What progress has been made toward meeting the goal of a 50% reduction in mortality relative to the baseline of average mortality in 1997-2002?*
3. *What is best methodology for setting recruitment and escapement targets for a watershed or estuary/bay area, taking into account cumulative impacts?*

A DFO Zonal Advisory Process meeting was held on September 2 and 3, 2010 in Ottawa (ON) to review the status of American Eel in Canada and to evaluate progress on achieving the management goals described in the Draft management plan. Participants at the science peer review meeting included scientists and fishery managers from DFO, scientists and managers from the Ontario Ministry of Natural Resources and the Quebec Ministère des Ressources naturelles et de la Faune, aboriginal peoples, invited external experts, and experts from power generation companies and from the fishing industry.

SUMMARY

- The American Eel (*Anguilla rostrata*) is a panmictic facultatively catadromous species, spawning in the Sargasso Sea. Juvenile and adult stages historically occurred in all accessible freshwater, estuarine and coastal areas connected to the Atlantic Ocean, as far north as the mid-Labrador coast and as far inland as Niagara Falls above Lake Ontario.
- The long-term goal expressed in the draft management plan is to rebuild overall abundance of American Eel in Canada to its level in the mid-1980s with the short term goal to reduce eel mortality from all sources by 50% relative to the 1997 to 2002 average.
- Region-specific status indices show that abundance relative to the 1980s is very low for Lake Ontario and upper St. Lawrence River stock, and either unchanged or increasing in the Atlantic Provinces.
- In Ontario and Quebec, the closure of fisheries and buyback of licences has resulted in reductions in total mortality of eels from fishing (measured as landings) of greater than 50% relative to mortality during 1997 to 2002.
- Declines in fisheries landings (by weight) of 27% were noted for the DFO Maritimes Region whereas average landings in DFO Gulf Region and in Newfoundland have increased or remained unchanged. Decreased landings in the Maritimes may be confounded by issues of underreporting. Increased landings in the southern Gulf of St. Lawrence despite tightening of management rules are attributed to increased abundance of eels in this region.
- There has not been any demonstrated progress in reducing mortality of eels during passage through turbines in medium and large hydroelectric generating stations.
- Changes in landings are an insufficient measure of the effectiveness of management measures in reducing mortality. With the objective to increase escapement in the long term, a reduction in mortality rate, expressed as a proportion of the population that is killed, is the appropriate measure of performance.
- Mortality rate reference points must be developed to assess in the long term the sustainable level of mortality, and in the short term the levels of mortality which will not preclude the rebuilding objective of American Eel abundance over its range.
- The region-specific abundance levels of the mid-1980s are considered reasonable objectives for the American Eel. This period corresponds to a mid-level of abundance, expressed either as landings in fisheries or as indicated by fisheries-independent indices.
- Loss of habitat associated with restricted fish passage, contaminants, ecosystem changes in Canadian waters and broad-scale oceanographic variation all contribute to the cumulative stress on American Eel in eastern Canada. The consequences of all of these to eel survival, reproduction, recruitment and rebuilding are poorly known.

BACKGROUND

Species Biology

The American Eel (*Anguilla rostrata*) is a panmictic facultatively catadromous species. The spawning ground for the entire species is in the Sargasso Sea, 500 to 1,000 km south of Bermuda. Larvae distribute widely toward coastal and estuarine waters with juvenile and adult stages found in freshwaters, estuaries and coastal marine waters of the western north Atlantic from Venezuela in the south, through the Gulf of Mexico, to Greenland and Iceland in the north, and in the six eastern provinces of Canada. In Canada, the historic range includes all accessible freshwater, estuarine and coastal areas connected to the Atlantic Ocean, as far north as the mid-Labrador coast and as far inland as Niagara Falls above Lake Ontario.

The glass eel stage has the typical serpentine form of the species but is not pigmented. Glass eels progressively acquire pigmentation as they move into continental waters, and are thereafter termed elvers. The elver stage is followed by an extended juvenile stage (yellow eel) lasting several years during which time sexual differentiation occurs. As they approach maturation, yellow eels transform into silver eels which have a number of morphological and physiological adaptations for long-distance migration to the spawning grounds in the southwestern Sargasso Sea. No adult spawning eels have ever been observed in the Sargasso Sea and the spawning areas are inferred from the distribution of larvae sampled at sea. The American Eel spawns only once and dies after spawning.

Available information indicates that neutral genetic markers of the American Eel show no geographic structure, which means that the species is panmictic. However, there is substantial variation in biological characteristics over the geographic range (Jessop 2010) and recent findings indicate that there is potential adaptive genetic variation in eels among locations in the species range of distribution. Recent studies have shown that some eels spend all of their life cycle in coastal waters, without a freshwater phase which had previously been considered obligatory for the species. The American Eel can be long-lived, up to 40 years of age or more, and grow to lengths exceeding 110 cm and weights exceeding 4 kg. Female silver eels are generally larger and older than male eels and comprise a higher proportion of the total stock in northern areas compared to southern areas.

Anthropogenic mortalities

Fishing and hydroelectric turbines are among the mortality sources that have a major impact on American Eel populations.

The American Eel is a species of particular importance to Aboriginal peoples in Canada. As well, it is fished commercially and sometimes recreationally in many parts of eastern Canada. Total reported annual harvests (from all users) ranged between 500 and 1,200 t between 1961 and 2003; but have declined from around 1,100 t annually in the late 1980s to around 500 t in 2003. The most recent estimate of total fisheries harvests in Canada was 459 t in 2007. There are extensive areas, mostly in the northern portion of its distribution in Canada, in which eels are not fished.

Eels can also be impacted by fish passage constraints. The presence of dams and other obstructions creates two types of impacts on eel populations: restriction of access to upstream habitat and the impeding of downstream migration, and (in the case of dams built for hydroelectric generation) mortality in turbines during downstream passage. Fish passage mortalities are a known problem in the St. Lawrence River mainstem and tributaries. The extent of the problem is unclear elsewhere.

Draft American Eel management plan

Exploitation activities of eels are managed by the three administrative regions of DFO in eastern Canada (Newfoundland and Labrador, Maritimes, Gulf) and by the provinces of Quebec and Ontario in their respective jurisdictions. The American Eel is identified as an Endangered Species under Ontario's *Endangered Species Act* (ESA), which prohibits the killing, harming, harassing, possessing, buying, selling, trading, leasing or transporting of this species.

In September 2004, DFO, the Ontario Ministry of Natural Resources and the Quebec Ministère des Ressources naturelles et de la Faune agreed to develop an integrated conservation plan to arrest significant population declines in American Eel stocks. An American Eel Management Plan, first drafted in 2006 (DFO 2009), was developed to strengthen management of American Eel, to halt abundance declines, and to foster recovery of the population (Canadian Eel Working Group 2009). Although presently, the draft management plan has not been officially adopted by the partnering agencies, management actions consistent with the plan have been initiated in every region. The long-term goal expressed in the draft management plan is to rebuild overall abundance of American Eel in Canada to its level in the mid-1980s. The immediate and short term goal is to reduce eel mortality from all sources by 50% relative to the 1997 to 2002 average. The draft management plan sets out actions with a focus on reducing mortality due to two known and significant sources (fishing, dams) while continuing to identify and establish mitigating actions for other sources of mortality.

ASSESSMENT

The following assessment was prepared in response to a request for science advice from DFO EFM and addresses the following points:

1) Based on region-specific abundance indices, assess the present status of American Eel in eastern Canada relative to the objective of rebuilding the overall abundance of American Eel to its level in the mid-1980s.
2) Describe the management measures that have been introduced in response to the objective of achieving a 50% reduction in anthropogenic mortality of American Eel.
3) Advise on the metric that should be used in the context of evaluating reductions in mortality (absolute number of animals or proportion of the stock).
4) To the extent possible, assess the level of mortality from all anthropogenic sources occurring on the stocks and to assess the level of mortality reduction which has been achieved.
5) To the extent possible, evaluate the appropriateness of existing management measures and advise on other measures that could be considered, and their contribution, to achieving the objectives of reducing anthropogenic mortality on American Eel and rebuilding the abundance as expressed in the draft management plan.

Status of American Eel in Canada

The status of American Eel relative to the mid-1980s is described using region-specific indicators of abundance (Cairns et al. 2008). Status is summarized by reference to the series average and the recent five-year average for the indicators.

Ontario

There are three ongoing status abundance indices for the Lake Ontario and upper St. Lawrence River stock (LO-uSLR): a long term count of juvenile eels ascending the eel ladder at the Moses-Saunders Generating Station (MSGS; Figure 1) (1974 – present), an index of abundance based on an electrofishing survey in eastern Lake Ontario (1984 – present), and a trawl survey index in the Bay of Quinte (Lake Ontario) (1972 – present).

Counts of ascending juvenile eels at the eel ladders of the MSGS averaged over 600,000 eels annually in the 1980s. The average abundance for the 2000s (11,949 eels per year) is only 2%

of the average observed in the 1980s and 1994 was the last year of sizeable movement (163,518 eels) of eels up the ladder (Figure 2).

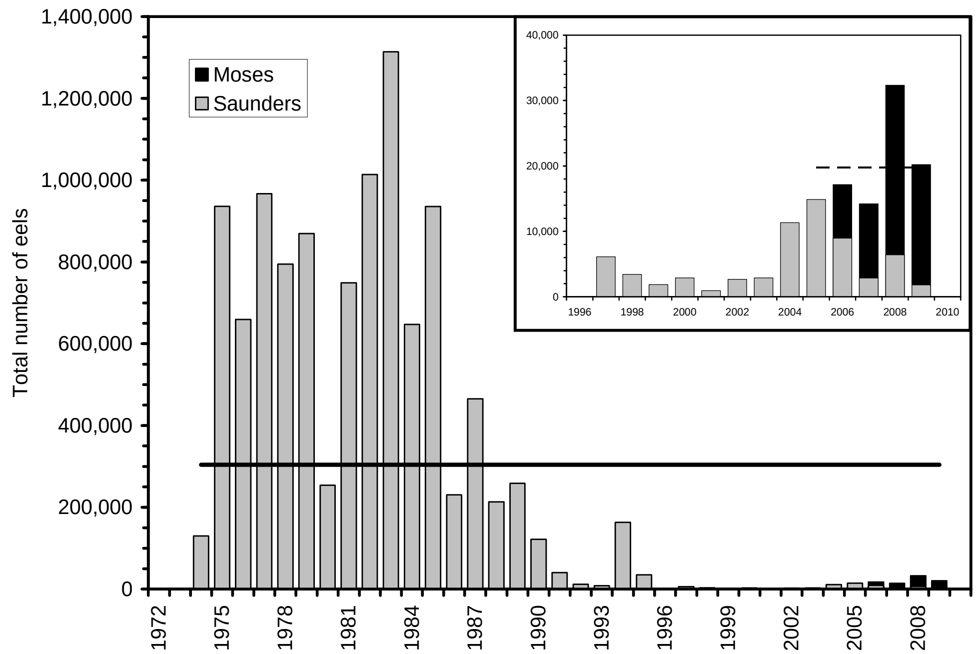

Figure 2. *Annual counts of eels ascending the eel ladders at the MSGS. No data were collected during 1996. In 2006, a second ladder (Moses on the US side of the dam) started operation. The solid horizontal line represents the time-series mean (solid) and the dashed line in the inset the recent five-year mean.*

Catches in the Bay of Quinte trawl survey index and the electrofishing index in the eastern part of Lake Ontario during the 2000s have declined to 1% and 3%, respectively, relative to the 1980s and are currently not significantly different from zero (Figure 3). Both of these indices are strongly correlated with the decline of the eel ladder counts at the MSGS. The best correlation (r=0.78) between immigration at the eel ladder and trawl catches in the Bay of Quinte was with a 4-year lag. Electrofishing catch was most strongly correlated (r=0.89) to the number of eels that ascended the ladder five years earlier. These indices clearly reveal a severe decline as a consequence of reduced recruitment to the Ontario waters of LO-uSLR.

All long-term Ontario abundance indices indicate that eels are at about 3% of their mid-1980s abundance, far from the objective of rebuilding stocks to mid-1980s levels.

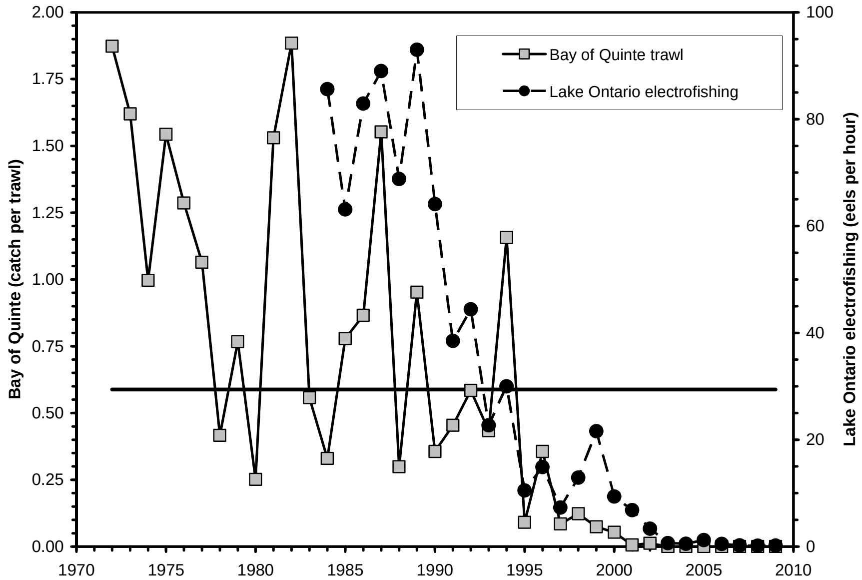

Figure 3. *American Eel abundance indices from trawling in the Bay of Quinte (grey squares) and boat electrofishing in eastern Lake Ontario (solid circles). The horizontal line represents the time-series mean for the Bay of Quinte index (0.59 eels per trawl) which on the figure overlaps the time series mean for the Lake Ontario electrofishing index (29.7 eels per hour). The recent five-year means (not shown) are at or near zero for both series*

Quebec

The status abundance indicator for eels of the upper St. Lawrence River is the long term count of juvenile American Eel ascending the eel ladder at the MSGS (Figure 2). As mentioned above, the average count of ascending juvenile eels in the 2000s has been only 2% of the average observed in the 1980s.

Other indicators of eel abundance from the upper St. Lawrence River do not extend as far back as the 1980s. A more recent time series of counts at the eel ladder in the Beauharnois Dam, just upstream of Montreal (Figure 1), indicates a recent increase in eel recruitment into Lake St. Francis since 2003 (Figure 4). A similar increase in counts of eels ascending the MSGS eel ladder was also noted since 2004 (Figure 2). There was an accumulation of eels below the Beauharnois Dam before 1993 and once the ladders became operational, eels ascending the ladders included some of the older and larger eels from previous years. In recent years, the eels passing the ladder have been smaller and of younger ages as seen by the decline in the mean length over the time series but still comprise a large number of year-classes (Figure 4).

A second index of abundance for the upper St. Lawrence is the counts of eels ascending the eel ladder of the Chambly Dam in the Richelieu River, tributary of the St. Lawrence River (Figure 1). Fish ladders were installed in the Chambly Dam in 1997 and fish passage was improved at St. Ours (downstream of Chambly) in 2001. The large count of eels ascending the ladder in 1998 is interpreted as passage of eels that had accumulated below the dam prior to the installation of a fish pass in 1997 (Figure 4). As at Beauharnois, eels sampled from the Chambly ladder represent a large number of age classes, ranging from 1 to 11 years old in the samples from 2009. As well, in 2009, 38% of the eels sampled at Chambly were migrant eels that had originally been stocked as glass eels in the Richelieu River above Chambly in 2005, 2006 or 2007, which confuses the interpretation of the trend in recruitment of eels at this facility.

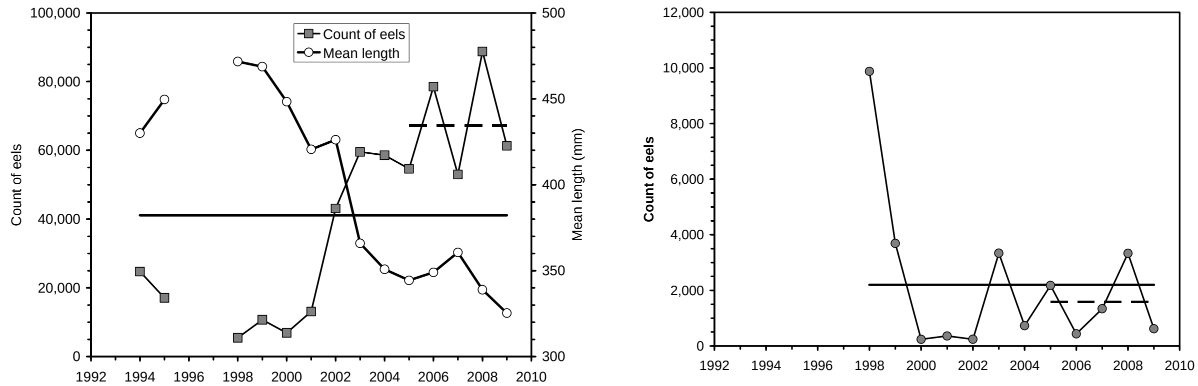

Figure 4. *Counts of juvenile eels ascending the eel ladders at the Beauharnois Dam in the St. Lawrence River (left panel) and at Chambly in the Richelieu River (right panel). Horizontal lines represent the series mean (solid) and the recent five-year mean (dashed)*

An index of eel abundance, consisting of a partial count of eels ascending a natural barrier, has also been developed for the Rivière Sud-ouest, tributary to the estuary of the St. Lawrence River (Verreault and Tardif 2009). Eels ascending the falls have a mean length of about 250 mm and ages ranging from 1 to 11 years with most eels being 2 to 6 years old. Partial counts over the short time series are highly variable, particularly in recent years (Figure 5). An index of year class strength has been calculated based on the age structure of sampled eels and it suggests a slight decline in relative year class strength for the 1998 to 2005 recruiting year classes (spawning year) (Figure 5).

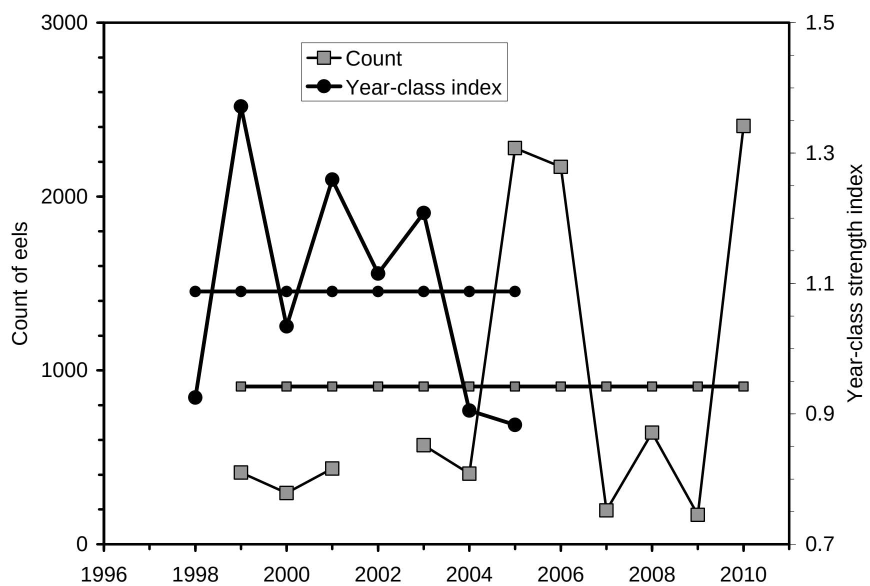

Figure 5. *Counts of eels and relative year class (spawning year) strength for the Rivière Sud-ouest, lower estuary of the St. Lawrence River. Horizontal lines represent the series mean.*

Gulf Region (DFO)

Indices of abundance of eels in freshwater are available from electrofishing surveys in two New Brunswick rivers, the Miramichi and the Restigouche (Figure 6). Both indices indicate that the average abundance in the 2000s has generally been higher than the abundance in the 1980s and higher than the long-term mean (Figure 6). Mean estimated eel densities were 0.50 eels per 100 m^2 during the 1972 to 2009 period and 0.80 eels per 100 m^2 during the 2005 to 2009 period for the Restigouche River. Mean densities of eels in the Miramichi River were 0.69 eel per 100 m^2 in the 1952 to 2009 period and 0.86 eel per 100 m^2 in the 2005 to 2009 period.

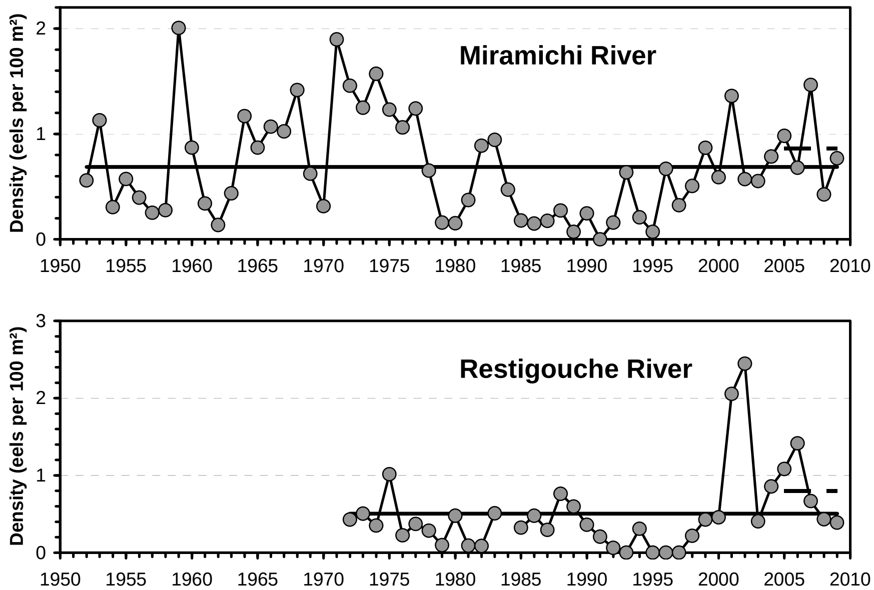

Figure 6. *Abundance indices (fish per 100 m^2) of American Eel from electrofishing surveys in two rivers of the southern Gulf of St. Lawrence. The solid horizontal line represents the time-series mean and the dashed line the recent five-year mean.*

Shorter fishery-dependent indices of catch per unit effort in three fisheries in Gulf Nova Scotia and PEI show a rising trend since the start of the time series in 1996 and 1997 (Figure 7). Mean CPUE in Gulf Nova Scotia was 1.96 kg per fyke net-day and 3.43 eels per spear-hour in 1997 to 2009, versus 2.56 kg per fyke net-day and 4.63 eels per spear-hour in 2005 to 2009. Mean CPUE in PEI was 0.82 kg per fyke net-day in 1996 to 2009 and 1.12 kg per fyke net-day in 2005 to 2009.

Considering these abundance indices, there has been a generally increasing trend in eel abundance in the southern Gulf of St. Lawrence during the 1997 to 2008 period.

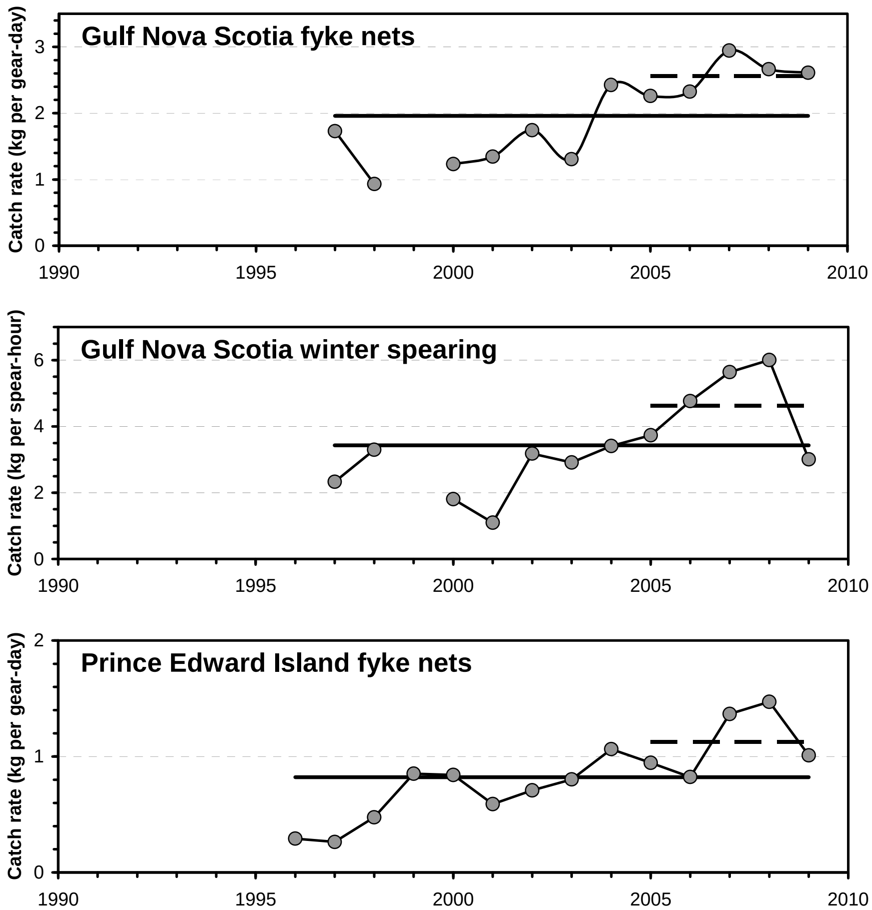

Figure 7. *Catch per unit effort indices in three commercial eel fisheries of the southern Gulf of St. Lawrence, 1996 to 2009. The solid horizontal line represents the time-series mean and the dashed line the recent five-year mean.*

Maritimes Region (DFO)

There are no indices of abundance based on fisheries in the DFO Maritimes Region which would allow assessment of present status relative to that of the 1980s. Estimates of abundance from electrofishing surveys in the St. Marys River (NS) since 2000 are lower than the abundances from two years in the 1980s and from those of the 1990s. In the LaHave River, abundance since 2003 is much lower than values observed in the prior decade (Figure 8). Shorter time series from New Brunswick electrofishing show no trend in abundance (Figure 8).

A recruitment index based on elver catches and counts in the East River - Chester (NS), beginning in 1996, shows wide annual fluctuations in elver recruitment but no trend into 2010 (Figure 9).

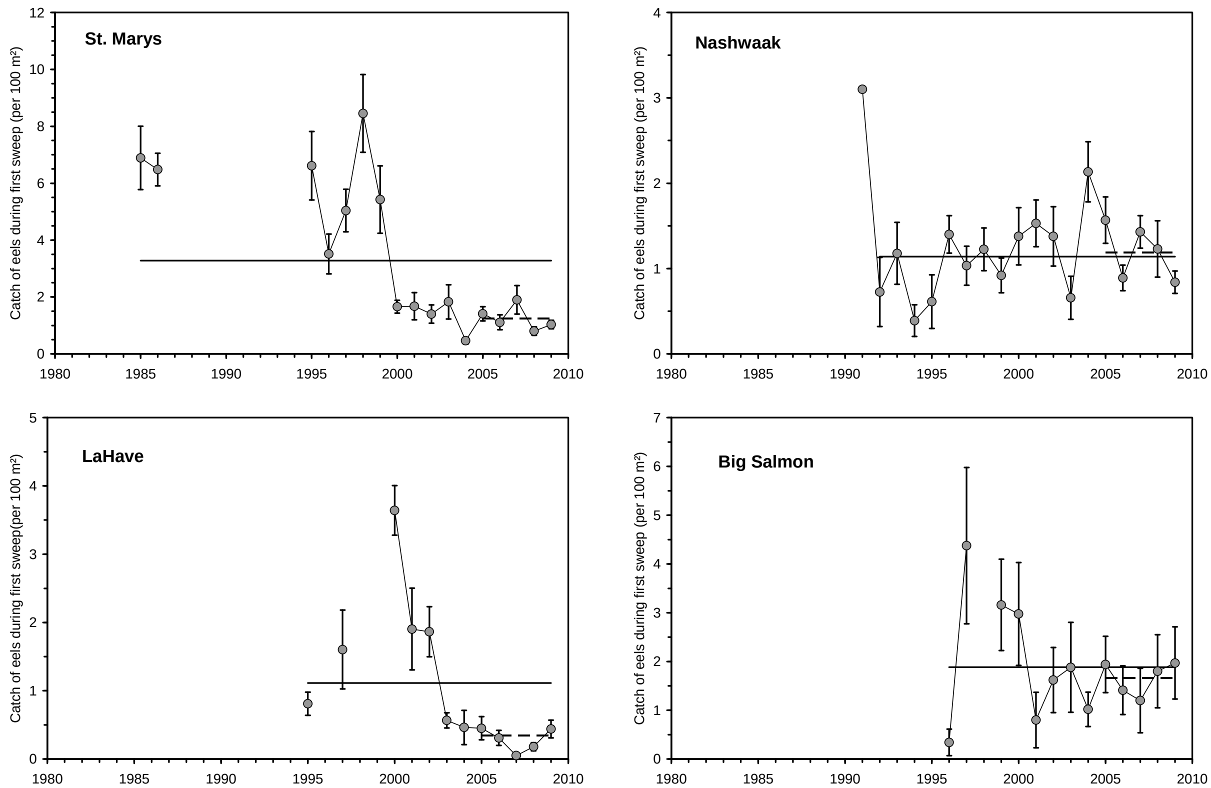

Figure 8. *Annual indices of abundance (catch of eels per 100 m² during the first sweep; mean +/- one std. dev.) of American Eel from electrofishing surveys in the St. Marys and LaHave rivers of Nova Scotia (left panels) and from the Nashwaak and Big Salmon rivers of the Bay of Fundy region of New Brunswick (right panels). The solid horizontal line represents the time-series mean and the dashed line the recent five-year mean.*

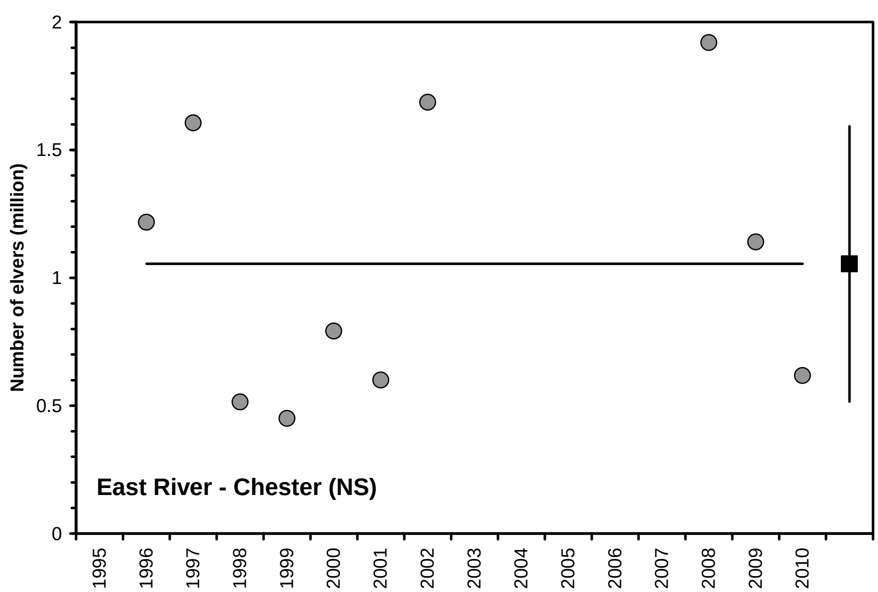

Figure 9. *Index of recruitment based on number of elvers in the East River – Chester (NS), 1996 to 2010. The solid square symbol is the average (+/- one std. dev.) of the time series.*

Newfoundland and Labrador

There are a limited number of fisheries-independent indices of eel abundance for Newfoundland and Labrador. Two electrofishing time series which covered the period of the 1980s ended in the mid to late 1990s (Figure 10). These series showed a declining trend in eel abundance.

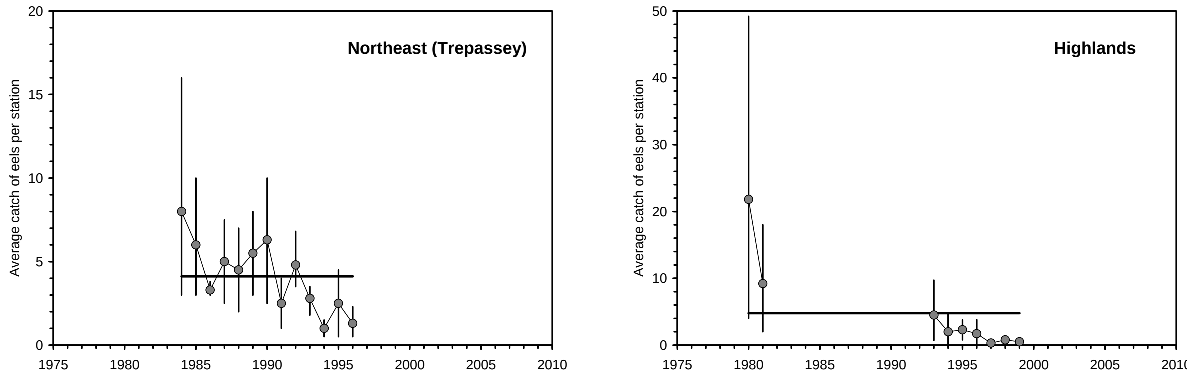

Figure 10. *Annual indices of abundance (catch per station, mean and 95% confidence interval) of American Eel from electrofishing surveys in the Northeast Brook (Trepassey) (left panel) and the Highlands River (right panel), Newfoundland relative to the series mean (solid horizontal line).*

More recent counts of eels at two salmonid counting fences covering a geographic range from 47.9º N to 51.2º N in Newfoundland show variable counts of eels over the period 1986 to the present (Figure 11). At Conne River the average annual count for the most recent five years was greater than the long term average. However, the opposite was true for Western Arm Brook.

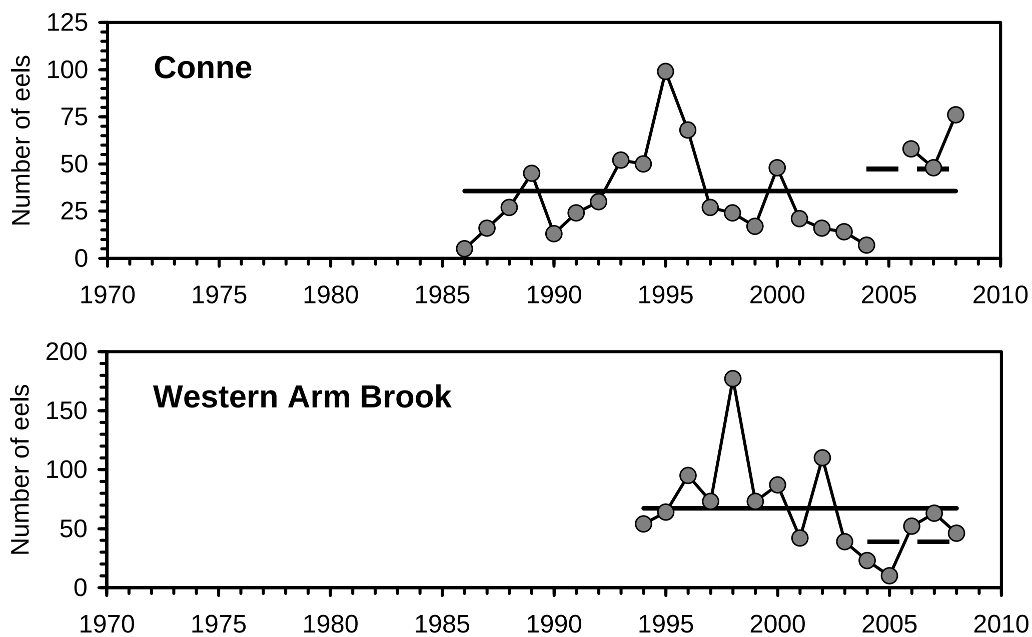

Figure 11. *Counts of American Eel at the salmonid counting facilities in Conne River and at Western Arm Brook, Newfoundland. The solid horizontal line represents the time-series mean and the dashed line the recent five-year mean.*

Based on these limited indicators, abundance is variable but may have stabilized in recent years.

Management measures introduced in response to the objective of achieving a 50% reduction in anthropogenic mortality of American Eel

Ontario

The American Eel is identified as an Endangered Species under Ontario's ESA 2007, which prohibits the killing, harming, harassing, possessing, buying, selling, trading, leasing or transporting of this species. In 2005, the Canadian Eel Steering Committee for Downstream Passage and Habitat Issues, developed a "Decision Analysis" aimed at developing mitigation measures to increase the number of eels migrating out of the LO-uSLR (Greig et al. 2006).

Ontario commercial eel fisheries were closed in 2004 and the recreational fishery for eels was closed in 2005. Silver eels escaping from Ontario are still exploited in St. Lawrence estuary fisheries; however, major reductions in these fisheries have been implemented (see Quebec section below).

A yellow eel trap and transport pilot project was initiated in 2008 as part of the Ontario Power Generation Action Plan for offsetting turbine mortality of American Eel at the MSGS. Large eels, >800 mm, captured as by-catch from existing multi-species commercial fisheries in Lake Ontario and Lake St. Francis (an enlargement of the St. Lawrence River upstream of Montreal), were transported around the two generating stations (MSGS, Beauharnois) or released back into Lake St. Francis (upstream of Beauharnois Dam). Between 2008 and 2010, over 3,000 eels have been transferred downstream of the MSGS and Beauharnois generating facilities. Moreover stocking with glass eels and elvers from Atlantic Canada began in 2006 as a means of maintaining the presence of eels in these waters. Approximately 4 million eels have been stocked into Lake Ontario. It is not yet known if these stocked eels will contribute to the spawning stock.

Quebec

In 1998, the commercial eel fishery in the Richelieu River was closed. Fishing licences were bought back during 2002 to 2009 in the St. Lawrence River, funded by the Provincial government (75%) and Hydro-Quebec (25%), as a partial compensation for turbine mortality. Between 2002 and 2007, 36 of 42 commercial hoop net fishing licences, targeting mostly yellow eels, were bought out from the Lac St-Pierre area, an enlargement of the St. Lawrence upstream of Trois-Rivières. In 2009, 46 of 67 silver eel commercial fishery licences in the lower St. Lawrence estuary were bought out.

Table 1. Chronology of licence buyout programs in the commercial fishery for American Eel in the Lac St-Pierre and lower estuary of the St. Lawrence River.

	Year of buyout	Licences bought out	Remaining licences
Lac St-Pierre (mostly yellow eels, few silver)	2002	6	36
	2005	17	19
	2006	1	18
	2007	12	6
Lower St. Lawrence estuary (silver eels)	2009	46	21

Glass eel stocking experiments were initiated in Lac Morin in eastern Quebec in 1999 (40,000 eels) and in the Richelieu River (tributary of the St. Lawrence River) (2.8 million eels) in 2005 to

2008. Fishways were made operational in the Richelieu River at Chambly in 1997 and Saint-Ours in 2001, opening up habitat to eels which had previously been lost (Verdon et al. 2003).

Gulf Region (DFO)

The minimum size in Gulf New Brunswick eel fisheries increased from 20 cm to 38.1 cm in 1996, to 46 cm in 2001, to 50 cm in 2004, and to 53 cm in 2005. Minimum retention sizes in the commercial eel fishery increased from 50 to 53 cm in 2007 in Gulf Nova Scotia, and from 50.8 to 53 cm in 2005 in PEI.

The commercial fyke net season was reduced from 214 days in 2004 to 140 days in 2006 in Gulf New Brunswick, and from 61 days to 54 days in 2007 in Gulf Nova Scotia. The season in PEI remained unchanged at 61 days.

In Gulf New Brunswick, regulatory definitions of fyke nets were enforced, to prevent use of extra-long leaders and gears with double funnels.

Commercial spearing for eels on PEI was closed in 2005. A requirement to retain all eels was imposed on the winter recreational spear fishery in 2005 in Gulf New Brunswick and in 2007 in Gulf Nova Scotia to prevent high-grading, i.e., the practice of discarding dead, injured, or small eels in order to provide room to catch larger eels within the daily bag limit.

Maritimes Region (DFO)

The minimum retention limit has been 35 cm (Total Length) since 2005, an increase from the previous 20 cm minimum length retention limit, except for southwestern New Brunswick (including the Saint John River) where the minimum retention size had been 30 cm since 1998. The number of commercial eel licences has been frozen since May 1993 and the number of recreational eel licences frozen at current levels since February 1997. Since May 2005, there is a mandatory requirement for escape mechanisms (1 inch by ½ inch openings) in fishing gears.

Elvers are defined in regulations as eels less than 10 cm (4”) in total length. In 1996, a total of nine experimental licences were issued and the number of elver licences has remained frozen at nine since 2005. The option for licence holders to apply for a 30% quota increase was removed (to be reviewed annually) and there was a 10% across the board quota reduction for each licence holder, the individual licence holder quota is now 900 kg. However, an additional 100 kg (10% of reduced quota) can be requested if that additional catch is destined for conservation stocking in Canadian waters.

Newfoundland and Labrador

A gear reduction program was implemented in 1997 which created a regional standard in terms of the number of gear units that could be fished. No new commercial eel licenses have been issued since 1998 and in 2004 the number of commercial eel licenses was reduced from 316 to 165. Fishers can only harvest from rivers that have been traditionally fished and identified in their licences. The season was reduced in 1998 by one month from an end date of November 30 to October 31. The minimum retention size limit for eels was increased in 2005 from 20 cm to 30 cm in the north, northeast and south coasts of Newfoundland (NAFO Divisions 3L, 3K and 3Ps). A mandatory logbook program was re-introduced in 2005 to provide better documentation of catch and effort.

Metric which should be used to evaluate reductions in mortality

Fisheries landings are reported in terms of weight which is not directly related to the total number of animals killed. Mean weight of eels in fisheries landings varies among the regions in eastern Canada and has also been shown to vary over time in the silver eel landings from the lower St. Lawrence River estuary fisheries. However, spawner contribution, at least as it relates to fecundity of females, does increase with eel size (weight) therefore landings when reported in terms of weight of silver eels do provide an indication of the amount of spawner potential killed.

The total number of animals killed during turbine passage has not been measured, but surveys in the tailwaters of the MSGS provide a mortality index. Directed studies can readily estimate the mortality rate associated with turbine passage but not necessarily the absolute number of animals killed unless the abundance of the migrating animals is known.

If abundance is decreasing, neither the mortality reduction nor the mortality rate reduction objective can guarantee that there will be increased escapement. However, for fisheries in which catch is known, a mortality rate assessment can provide estimates of the number of animals killed and the number of animals surviving and therefore an evaluation of the effectiveness of the management measures in reducing mortality and increasing escapement regardless of the trend in abundance.

The draft management plan does not indicate whether the reduction in mortality objective is in terms of the number of animals killed or the rate of mortality (expressed as the proportion of the stock which is killed). Reference points to guide management are derived in terms of mortality rates rather than in terms of numbers killed. Mortality rates are more meaningful than absolute numbers in the context of population dynamics. If the objective is to increase escapement in the long-term, then a reduction in mortality rate is the favoured measure and the farther downstream in a river the reduction is applied, the more efficient the measure will be in terms of increasing escapement.

The estimation of rates requires more assessment effort. There may be existing literature to inform on the expected mortality rates during downstream passage based on the type of facility and the eel life stage. However that is not the case for fisheries.

Assessment of the level of mortality from all anthropogenic sources occurring on the stocks and assessment of the level of mortality reduction that has been achieved

Ontario

Commercial landings of eels during 1997 to 2002 averaged 23.8 t (range: 11 to 41 t) (Figure 12). The commercial eel fishery in Lake Ontario was closed in 2004.

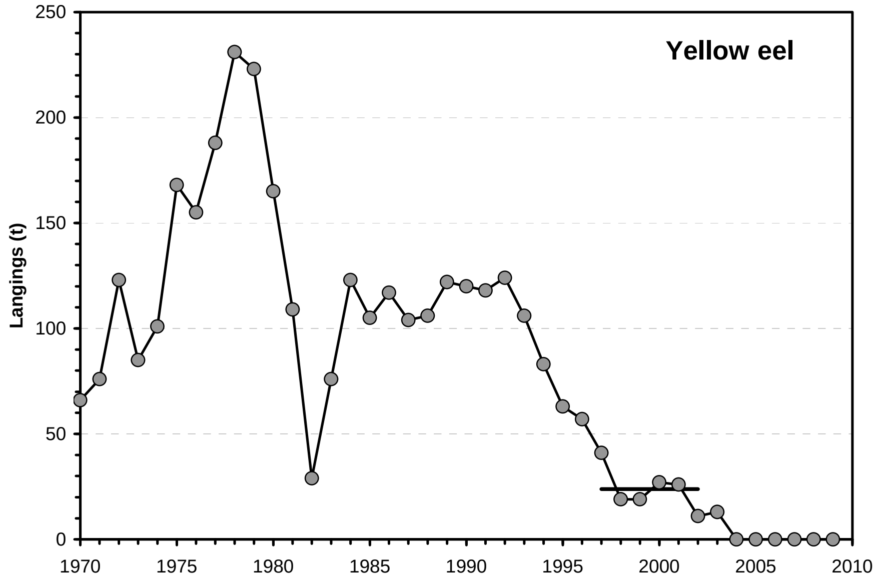

Figure 12. *Commercial fishery eel landings from Lake Ontario, 1970 to 2004. The commercial fishery was closed in 2004. The solid horizontal line is the average landing for the period 1997 to 2002.*

Hydroelectric facilities on the two main American Eel watercourses bordering Ontario are the only remaining direct source of anthropogenic mortality. Turbine-related mortality of eels at the MSGS, located on the upper St. Lawrence River, was estimated in one year at 26.4% and mortality at the Beauharnois Dam downstream of Lake St. Francis (in Quebec) has been estimated at 18%. Cumulative mortality of eels leaving Lake Ontario from the two dams was 40%. No mortality estimates are available for generating stations on the Ottawa River, although mortality does occur as dead eels have been observed downstream of some of the facilities. Mortality rates for smaller, higher speed turbines, such as those on the Ottawa River, are much higher than for turbines on the St. Lawrence River (EPRI 2001).

Based on modeling and a mark-recapture population estimate of eels descending the St. Lawrence River at Quebec City, it was estimated that less than half a million eels left the LO-uSLR annually during 1996 and 1997. This estimate was used to calculate the number of silver eels leaving the system during 1997 to 2010 by extrapolation of the eel ladder count (with a 14 year lag), Bay of Quinte trawling (with a 5 year lag), and electrofishing (with a 9 year lag) indices of abundance.

Based on this model, the average rate of anthropogenic mortality of eels in the LO-uSLR during 1997 to 2002 was 31% (45,270 fish). The fishing mortality rate during this time period was estimated at about 6% while turbine mortality accounted for 24% of the measured anthropogenic mortality of the silver eel stock leaving LO-uSLR. Since the closure of the commercial fishery in Ontario in 2004, the average rate of anthropogenic mortality of eels in the LO-uSLR has been 16% (4,359 fish) about half the value for 1997 to 2002, with all the mortalities attributed to turbines. The reduced mortality rate due to turbines relative to the values in the mid 1990s is the result of a proportionally higher production of eels in Lake St. Francis compared to Lake Ontario, given that eels from Lake St. Francis have to transit only one hydroelectric dam (Beauharnois) during their downstream migration. All these mortality calculations exclude the lower St. Lawrence River silver eel fisheries and turbine mortality at Beauharnois GS. On the other hand, the mortality rate of eels passing through turbines is positively correlated with length and the observed increase in mean weight (and presumably length) in the fisheries landings from the LO-uSLR suggests that there may have been an increase in turbine mortality rate.

The transport of about 1,200 eels annually around the two generating stations during the three years of operation to date is estimated to have resulted in a reduction in turbine mortality of about 245 eels per year.

Quebec

Anthropogenic mortality of eels in Quebec is due primarily to turbines and fisheries. The mortality of eels from Lake St. Francis and from Lake Ontario passing through the Beauharnois Dam turbines was estimated at 18%. Annual estimates are not available but no changes in structure and operation have occurred that would suggest changes in the turbine mortality rate in recent years.

Fishing licences were bought back during 2002 to 2009 in the St. Lawrence River. These reductions in effort, along with a decline in abundance of eels from Lake Ontario and the uSLR would have contributed to reduced catches in recent years. During 1997 to 2002, the mean catch of yellow eels, primarily from the Lac St.-Pierre fishery, was 29.5 t (range: 20 to 37 t). During the recent 5-year period, the mean catch of yellow eels was 8.7 t, a 71% reduction from the 1997 to 2002 mean (Figure 13). Silver eels from Lake Ontario and the uSLR are primarily captured in the lower estuary fisheries of the St. Lawrence River. During 1997 to 2002, the mean catch of silver eels was 160.7 t (range: 133 to 205 t) (Figure 13) compared to a mean catch of 80.8 t (range: 53 to 99 t) during 2005 to 2009, a reduction of 50% relative to 1997 to 2002 (Figure 13). For both the yellow and silver eel phases, the total reduction of the catch in 2005 to 2009, compared to the 1997 to 2002 reference period, is 53% in the Québec waters of the St. Lawrence River.

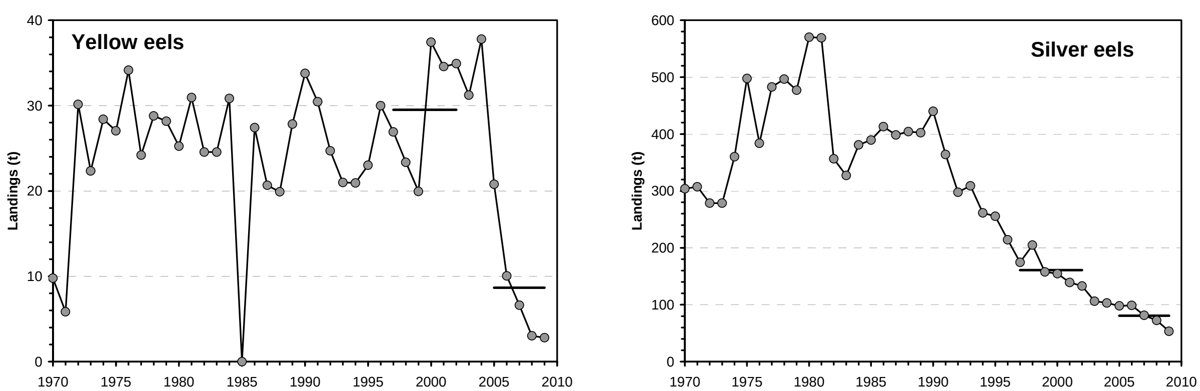

Figure 13. *Commercial fishery landings of yellow eel primarily from Lac St- Pierre (left panel) and silver eel primarily from the lower St. Lawrence River (right panel) for 1970 to 2009. The solid horizontal lines represent the mean landings for 1997 to 2002 and 2005 to 2009 periods.*

The number of silver eels in 2009 which were predicted to have been not been killed in the lower St. Lawrence estuary fishery as a direct result of the buyback of silver eel fishery licences in 2009 was calculated using the significant (r^2 = 0.94) negative linear regression of catches of silver eel versus year for the period 1998 to 2008. For 2009, the predicted catch in the absence of buyback would have been 57.5 t compared to a realized catch of 23.8 t, or a saving of 33.7 t of silver eel spawners. For this portion of the fishery, the reduction in absolute mortality between 2008 and 2009 was 58.6%.

Gulf Region (DFO)

The most important anthropogenic source of mortality for American Eel in Gulf Region is from fisheries. Fisheries harvest mostly yellow eels with a small component of silver eels in some fishing areas. Reported landings in Gulf Region averaged 127.9 t in 1997 to 2002 and 187.0 t in 2004 to 2008, which is an increase of 46.2% (Figure 14). Biomass of eels in shallow (<3 m deep) and sheltered waters of Gulf Region as estimated by glass bottom boat surveys was 2,158 t in 2007 and 2008. Biomass estimates for earlier years were adjusted by the slopes of regressions of population indicators (Figure 7) against year. Reported landings as a percentage of biomass within the glass bottom boat survey area were 8.4% for 1997-2002 and 6.7% in 2004-2008, which is a decrease of 20.1% (Figure 14). These results indicate that management restrictions imposed after 2003 were insufficient to reduce fisheries landings during a time of increasing biomass. However, landings as a percent of the available biomass decreased by 20%, which reflects a combination of rising biomass and management measures during the period of comparison.

The southern Gulf of St. Lawrence is not heavily industrialized, suggesting that its tidal waters may be less subject to chemical contamination than American Eel habitat in the interior of the continent. Nevertheless, contaminants from forestry, agricultural, and municipal sources pose risk to the region's aquatic life. The southern Gulf of St. Lawrence contains no dams known to be equipped with turbines. Dams are common on Prince Edward Island, but are probably not harmful to eel populations because eels readily colonize their reservoirs.

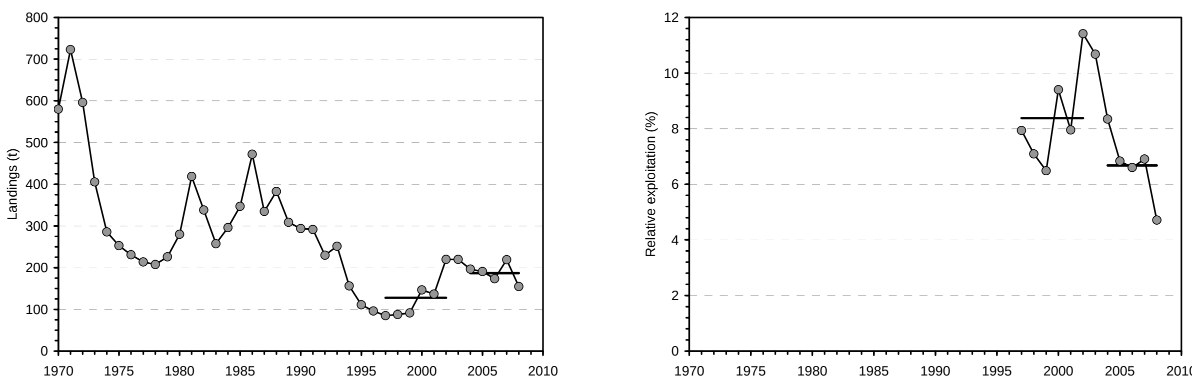

Figure 14. *Reported landings (t) of American Eel from the southern Gulf of St. Lawrence for 1970 to 2008 (left panel) and relative exploitation rate (%) (right panel) in the southern Gulf of St. Lawrence during 1997 to 2008. The horizontal lines represent the means of the periods 1997 to 2002 and 2004 to 2008.*

Maritimes Region (DFO)

Only mortalities associated with fisheries can be quantified (catches) but records after 2007 are not yet available.

Anthropogenic sources of mortality of the American Eel in the Maritimes Region occur primarily through fisheries and turbines. A single eel migration study at the Magaguadavic River indicated that 76% (19 of 25 tagged animals) of the migrating eels passed through the turbines and all died (Carr and Whoriskey 2008). There are no estimates of turbine or downstream passage mortality rates and total mortalities for the remaining facilities in the region.

Reported landings of yellow and silver eels in the Maritimes Region averaged 142 t in 1997 to 2002 and 103 t in 2004 to 2007, a decrease of 27% (Figure 15). There is concern that the reported fisheries landings in 2004 to 2007 are incomplete as a result of the low return rate of logbooks in those years. Measures have been implemented to address the non-reporting in the fishery but the effectiveness of these measures has not been evaluated to date pending the availability of the statistics. Landings of elvers are complete and increased by 18% during 2004 to 2007 relative to the average landings during 1997 to 2002 (Figure 15).

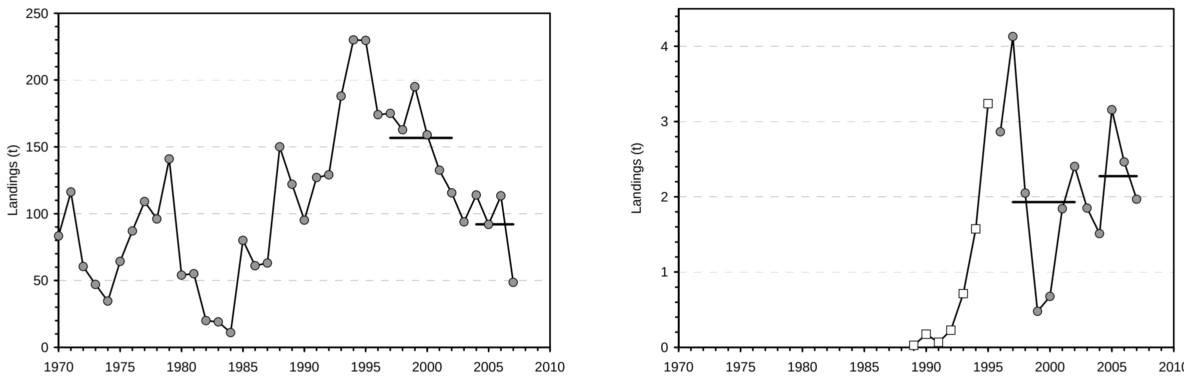

Figure 15. *Reported landings (t) of yellow and silver American Eel (left panel) and elvers (right panel) from the DFO Maritimes Region for 1970 to 2007. The horizontal lines represent the means of the periods 1997 to 2002 and 2004 to 2007. During 1989 to 1995, the elver fishery was an exploratory fishery. Since 1996, the elver fishery has been managed under an integrated fisheries management plan.*

Large portions of the southern Uplands portion of Nova Scotia rivers are impacted by acid deposition and low pH. Based on preliminary short term survival experiments, eels appear tolerant of acidic conditions.

The swimbladder parasite, which is known to negatively effect survival of seaward migrating eels, is now present and broadly distributed, but of low prevalence and intensity in eels in the region. The effect on the overall stock is unknown.

Newfoundland and Labrador

There are no estimates of turbine or downstream passage mortality rates and total mortalities for any facilities in the region. Only mortalities associated with fisheries can be quantified. Landings during the 1997 to 2002 period averaged 62 t. During the recent five-year period (2005 to 2009), landings averaged 59 t, a decrease of 5% from the average of the 1997 to 2002 period (Figure 16). The landings of 33 t in 2009 represent a 47% reduction from the 1997 to 2002 average. This reduction can be mostly attributed to market conditions.

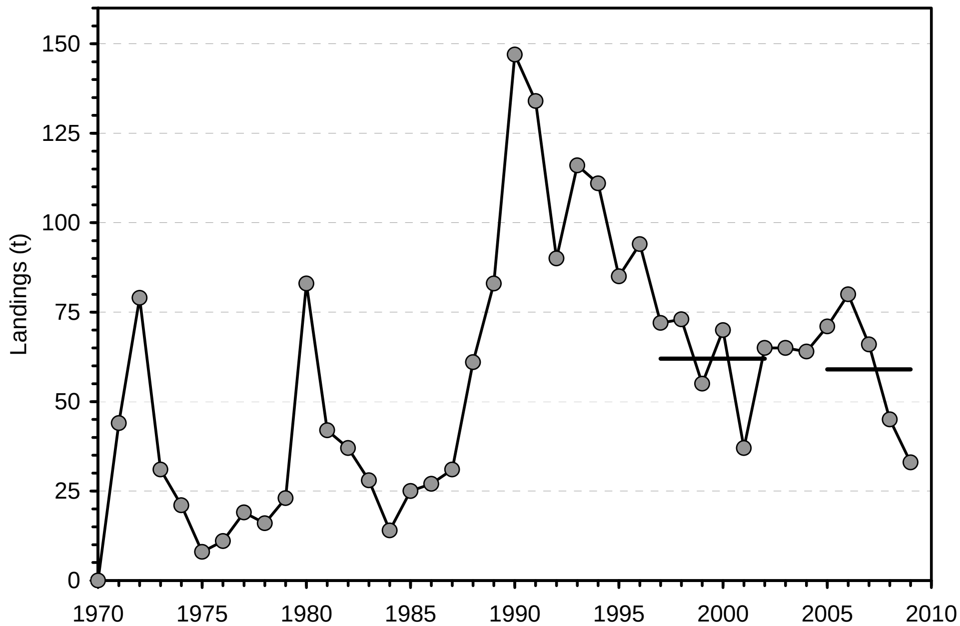

Figure 16. *Reported landings (t) of American Eel from the DFO Newfoundland and Labrador Region for 1970 to 2009. The horizontal lines represent the means of the periods 1997 to 2002 and 2005 to 2009.*

Summary by region and eastern Canada

With the exception of the DFO Gulf Region, reductions in absolute mortality of yellow and silver eels were realized during the recent five years relative to the 1997 to 2002 base period (Table 2). For all of eastern Canada, the reduction in mortality has been greater than 20%. The lower mortality rate for the LO-uSL stock is not due to changes in turbine mortality rate but due to a higher proportion of eels now being produced below MSGS.

Table 2. Summary of the regional reductions in absolute mortality and in the rate of mortality of yellow and silver eels during the recent five year period relative to the 1997 to 2002 base period. For Ontario, the changes in absolute mortality and mortality rate refer to silver eel mortality associated with fishing in Lake Ontario and from hydro-dams. For all the other regions, the mortalities and rates are in fisheries only. For the eastern Canada estimate, an average weight of 1 kg was assumed for eels in Ontario

	Yellow and silver eels	
Region	Change in absolute mortality (weight)	Change in mortality rate (number)
Ontario	- 90%[1]	- 50%
Quebec	- 53%	
Gulf	+ 46%	- 20%
Maritimes	- 27%	
Newfoundland	- 5%	
Eastern Canada	- 22%	

[1] number of eels

Appropriateness of the existing management measures and other measures that could be considered to achieve the objectives of reducing anthropogenic mortality and rebuilding abundance

In the southern Gulf of St. Lawrence, fisheries were subject to increased restrictions including reductions in seasons and increases in minimum size but landings in recent years were higher than the mean of the 1997 to 2002 baseline period. It is difficult to achieve reductions in fisheries landings during a time of rising abundance. There are a large number of inactive licences in many parts of eastern Canada. Buyback programs in Quebec that reduced the silver eel fishery licences in the lower estuary are considered to have been effective at reducing mortality of silver eels of the St. Lawrence River basin stock (including the LO-uSLR stock).

For the LO-uSLR stock, a decision analysis (DA) process was conducted to identify the best mitigation measure(s) in the face of uncertainty about eel ecology and the likely effectiveness of potential mitigation measures. Fisheries reductions and stocking were identified as the most cost effective and feasible methods, and had the lowest uncertainty of outcome. Trap and transport was identified as the most desirable of the alternatives that directly addressed turbine mortality, but its cost effectiveness, feasibility, and uncertainty were poor relative to stocking and fisheries reduction alternatives (Greig et al. 2006).

The closure of commercial and recreational American Eel fisheries in Ontario has eliminated most fishery-related mortality in that province. Stocked eels in Ontario and Quebec waters are surviving, growing quickly, and dispersing broadly in the watershed. However, there remain important questions with the stocking program including whether the characteristics of stocked eels will mimic those of eels which naturally recruited to the region. These characteristics include: exclusively female, of older age, of similar migration timing, and very large size at silvering with energy stores for the long migration to the spawning grounds. Finally, it is uncertain whether ongoing access to disease- and parasite-free glass eels for stocking will be consistent, timely, and cost-effective. The risk of introducing diseases and parasites is not negligible.

A pilot project to trap and transport eels around the physical barriers on the upper St. Lawrence River, with the objective of saving eels from turbine mortality, is under way. So far, it has been proven difficult to collect sufficient numbers of large yellow eels from the bycatch in existing commercial fisheries in Lake Ontario and it seems unlikely that the numbers of eel transported can be increased significantly with the current approach to capturing them. Alternative techniques to capture eels in the uSLR are being explored. Initial results do suggest that significant numbers of the transported eels migrate downstream and appear to be maturing normally.

Reference mortality levels for the American Eel

In the absence of reference levels for managing mortalities, it is unknown whether the actions associated with reducing mortality on American eel are sufficient to achieve the long-term goal to rebuild eel abundance to levels observed in the mid 1980s.

To be consistent with the Precautionary Approach (DFO 2009), reference points should be developed to assess stock status and guide management decisions. Since the level of anthropogenic stresses varies across the species range and the management of these stresses would occur at local rather than national and international scales, reference points provide simple and cost-effective approaches to guide these management decisions and are required at local scales.

ICES (2001) described Spawner per Recruit (SPR) modelling to define mortality reference points for the American Eel and proposed the mortality rate that results in 30%SPR as a default value for a limit reference point and the mortality rate that results in 50%SPR as a target reference point. SPR analysis makes no assumption about the recruitment obtained from a spawning escapement. It only considers how many spawners are produced from recruited eels and assumes that average life history characteristics are not modified by the relative size of the recruitment, i.e. no density-dependent effects.

Due to the phenotypic plasticity of the American Eel and the association of some of these characteristics (sex ratio, growth rates, length at maturity, age at maturity, natural mortality) with geographic region and rearing habitat, SPR analysis should be done at the geographic scale that corresponds to a set of homogeneous life history characteristics, termed a stock complex. The reference points derived using SPR depend upon the life history characteristics of the stock complex as well as the timing of the anthropogenic stressor in the eel's life cycle. For example, the annual fishing rate corresponding to 30%SPR for a yellow eel fishery would be less than that for a silver eel fishery because yellow eels are typically exposed to fishing pressure over several years. The SPR model analysis can be extended to incorporate complex geographic structuring and multiple anthropogenic stressors.

Most of the life history data required to conduct SPR analyses and define the mortality rate reference points for the American Eel in eastern Canada are broadly available or readily obtainable with dedicated monitoring programs. The accumulation of these reference points and implementation of management-based SPR analysis would benefit the species as a whole because the objective is to ensure a similar level of relative spawning escapement from each region. Defining these reference points for specific anthropogenic stressors will require a directed science peer review meeting.

Defining only mortality rate reference levels can be inadequate as it does not account for depensatory or Allee effects which can be expressed at low biomass levels. Defining biomass reference points for the eel remains a challenge.

Uncertainty and knowledge gaps

Eel fisheries occur on small scales over broad geographic areas and the reported fisheries landings in the Maritime Provinces and Newfoundland are considered incomplete. Logbook programs are in place in most of these regions but the programs are either voluntary, or not widely enforced when compulsory. Incomplete data on landings constrains the assessment and interpretation of changes in mortality of eels resulting from management measures.

Fishery-dependent indicators of abundance, generally expressed as catch relative to a unit of effort, have not been assessed for their bias. Effort remains difficult to quantify; it is often missing, or when present, is expressed in units that may not be scaled with the probability of capture of eels.

There are limited fishery-independent indicators of abundance. With the exception of the indicators for LO-uSLR, the majority of indicators are from electrofishing surveys in rivers designed to monitor salmonid abundance. For these surveys, the indices have not been corrected for any of the habitat features which could correlate with eel abundance, such as elevation, stream order, and distance above the head of tide. Some of these indicators are collected from watersheds that are not fished or impacted by fish passage or turbine mortalities.

Consequently, they may not be relevant in evaluating management measures but can serve as indicators of unimpacted systems.

All the indicators of abundance in this report, with the exception of the elver indices, are yellow eel indicators and in any year comprise multiple ages and year-classes. For example, the eels ascending the eel ladders at Beauharnois Dam (Figure 4) comprised eels ranging in age from 2 to 10 years in 2009, with 90% of the samples aged 2 to 6 years. Interpreting year-class specific strength from these is not appropriate.

A limited number of studies have evaluated mortality rates from fisheries and from downstream passage through turbines. Few of these studies have been replicated over time; directed studies to estimate the exploitation rate in the silver eel fisheries downstream of Quebec City were conducted in 1996 and 1997 (Caron et al. 2003) and a similar study is being conducted in 2010. Such studies are essential in assessing stock status and the effectiveness of management measures.

No mortality and biomass reference points have been defined to date. As a result, it is difficult to evaluate progress on meeting management objectives or to advise on appropriate management measures.

Injuries sustained during downstream migration and in escapement from fishing gears or during sorting of catches can result in delayed mortality, including increased susceptibility to predation. These effects have not been evaluated.

Numerous other factors including upstream passage constraints, contaminants, ecosystem changes, parasites, and changes in oceanographic conditions may be contributing to mortality and abundance declines of the American Eel, in addition to fishing and turbines. The cumulative mortality on American Eel of all these factors is not known.

CONCLUSIONS AND ADVICE

The decline in the American Eel has been particularly severe in the upper St. Lawrence watershed (LO-uSLR), including the historically important production areas of Lake Ontario, the Richelieu River, and the Ottawa River. The decline in landings in the silver eel fisheries of the lower St. Lawrence River reflects in part decreased production from the LO-uSLR because historically the catches in these fisheries were predominantly of eels produced from this area. The increased conservation concern for the American Eel is that the production from LO-uSLR has declined to 2% of the levels of the mid 1980s and this production consists entirely of large-sized females whose contribution to the panmictic spawning stock is considered to have historically been biologically significant.

Few abundance indicators of the American Eel in Canada extend from the 1980s to the present. All three Ontario abundance indices are presently at about 3% of the levels measured in the mid-1980s. Counts at the eel ladders at the Beauharnois dam upstream of Montreal, as well as at the MSGS, indicate a recent increase in eel recruitment into LO-uSLR since 2003, but are still about two orders of magnitude below the 1980s level. The two long-term indices of abundance of eels in freshwater from the southern Gulf of St. Lawrence indicate that average abundance since 2000 has generally been higher than the abundance in the 1980s and higher than the long-term mean. Indices of abundance from electrofishing surveys in rivers of the Atlantic coast of Nova Scotia are lower since 2000 than the abundances indices derived from limited sampling in the 1980s and from those of the 1990s. Shorter time series from Bay of Fundy (New Brunswick) rivers show no trend in abundance. Overall, region-specific status indicators are at similar levels to those reported in COSEWIC (2006); very low abundance for LO-uSLR, and variable trends from declines, no change, or increases, in the Atlantic provinces.

As a result of the very low abundance of yellow eels in Lake Ontario and the reduced numbers of potentially migrating silver eels from Lake Ontario, the number of eels killed during passage through turbines is estimated to have been reduced by more than 50%. The proportion of migrating silver eels killed in turbines is expected to have increased slightly due to increases in length of individual migrating eels.

In Ontario and Quebec, the closure of fisheries and buyback of licences has resulted in reductions in total mortality of eels from fishing (measured as landings) in the past five years of greater than 50% relative to the mortality during 1997 to 2002. The number of silver eels killed in lower St. Lawrence estuary fisheries has also declined by greater than 50% but it is not known how much the exploitation rate in this fishery has been reduced as a result of the licence buyback program. Landings in fisheries from the DFO Maritimes Region have declined by 27% from the base period whereas landings in DFO Gulf Region and in Newfoundland have increased or remained unchanged. Increased landings in the southern Gulf of St. Lawrence despite changes in management are attributed to increased abundance of eel in this region over the period of comparison.

Changes in landings are an insufficient measure of the effectiveness of management measures in reducing mortality. If the objective is to increase escapement in the long-term, then a reduction in mortality rate, expressed as a proportion of the population which is killed, is the appropriate measure of performance. There are very few assessments of exploitation rates in directed fisheries and these are not routine activities in any region of eastern Canada.

Research in reducing turbine mortalities of eels is ongoing but to date there has not been any demonstrated progress in reducing mortality rates of eels during passage through turbines on large river systems such as the St. Lawrence. There are very few estimates of turbine mortality, they are available for only a few facilities, and with little to no temporal replication. Mortality rates in turbines are unlikely to have been reduced from 1997 to the present with the exception of a few smaller river systems (for example, the Rimouski River where protection grids were installed upstream of the turbine intakes).

Mortality rate reference points, at a minimum, must be developed to assess in the long term the sustainable level of mortality, and in the short term the levels of mortality which will not preclude the rebuilding objective of the American Eel abundance over its range. Reference points are also required to assess whether the short-term objective of a 50% reduction in mortality is an appropriate goal to rebuild abundance in regions where the eel stock has collapsed and to protect stocks in regions where they are still exploited. The region-specific abundance levels of the mid 1980s are considered reasonable objectives for the American Eel. In most regions, this period corresponds to a mid-level of abundance, expressed either as landings in fisheries or as indicated in fisheries-independent indices.

Constraints on American Eel abundance extend beyond fishing and turbine mortality. Loss of habitat associated with restricted fish passage, contaminants, ecosystem changes in Canadian waters and broad-scale oceanographic variation all contribute to the cumulative stress on American Eel in Canada. The consequences of these additional factors to eel survival, reproduction, recruitment and rebuilding are poorly known.

OTHER CONSIDERATIONS

Although mortality from fishing in some areas may be substantial, there remain extensive areas of production in eastern Canada in which eels are not subjected to fishing or fish passage mortality. An evaluation of total anthropogenic mortality on the eastern Canadian eel stock must consider geographic variability in anthropogenic impact. Eel fisheries are unevenly distributed in eastern Canada. The portion of the eastern Canadian coastline that is within 1 km of eel fishing sites is 7%. This value varies from about 1% in Quebec and the Island of Newfoundland to 35% in the southern Gulf of St. Lawrence. Large sectors of eastern Canada are free of fishing activities, particularly the northern Gulf of St. Lawrence. Broad-scale evaluations of mortality due to fish passage in eastern Canada have not been completed. However, dams, including hydroelectric dams, are absent from substantial areas of eastern Canada.

Direct impacts of habitat, productivity and food-web alterations on American Eel remain speculative but in many areas of eastern Canada, poor land use practices associated with intensive timber harvest, farming practices and urbanization of watersheds, have resulted in impaired environmental quality. Changes in the ecosystem have also been noted, particularly in the Lake Ontario - St. Lawrence River system, associated with the invasion of dreissenid mussels (e.g., zebra mussel; *Dreissena polymorph*a), reductions in alewife abundance, and the emergence of gobies as the dominant benthic fish species. The potential impacts on eels from these factors are considered to be most important in the freshwater habitats.

A wide variety of chemicals may affect eel fertility, survival, and migration success. Concerns that contaminant burdens may influence reproductive success and possibly lead to population declines have received more research attention in the European than in the American Eel (Geeraerts and Belpaire 2010). Contaminant loads in eels in the St. Lawrence River system are at elevated levels but the consequences of this to eel survival, reproduction and recruitment is not well understood or quantified (Hodson et al. 1994; Couillard et al. 1997).

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