Advisory Committee on Fisheries Management **ICES CM 2001/ACFM:03**

REPORT OF THE

EIFAC/ICES WORKING GROUP ON EELS

St. Andrews, N.B., Canada
28 August - 1 September 2000

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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TABLE OF CONTENTS

0

1 INTRODUCTION

1.1 Main Tasks

At its 1999 Statutory Meeting, ICES resolved (C. Res. 1999/2ACFM13) that the EIFAC/ICES Working Group on Eels [WGEEL](Chair: Dr L. Marshall, Canada) will meet in St. Andrews NB, Canada from 28 August to 1 September, in 2000 to consider questions posed to ICES by the governments of Canada and USA. The terms of reference and sections of the report, in which the answers are provided, follow.

Terms of Reference	Section
a) assess trends in recruitment and their causes, in fisheries and the effects on stock and yield of the American eel;	2, 3
b) investigate the impact of fisheries on American eel in selected systems, especially with regard to the consequences for spawner escapement;	3
c) investigate the options for developing escapement targets for American eel for selected systems;	4
d) define relevant units where these targets would apply;	5
e) suggest type of management actions that may lead to the required escapement of American eel;	6, 8
f) advise on international coordination of research on American eel in the future.	7

The Working Group considered 25 Working Documents (Appendix 1) submitted by 21 participants; other references cited in the report are given in Appendix 2. Complete addresses for five authors who provided information used by the Working Group that was not referenceable due to previous publishing commitments, appear in Appendix 3. Definitions of key life history terms and fishing gear for the American eel, *Anguilla rostrata*, are provided in Appendix 4.

1.2 Participants

Boubée, J	New Zealand
Cairns, D.	Canada
Caron, F.	Canada
Casselman, J.	Canada
Castonguay, M.	Canada
Chaput, G.	Canada
Dekker, W	Netherlands
Jessop, B.	Canada
Marshall, L.	Canada (Chair)
Mathers, A	Canada
McCleave, J.	USA
Meerburg, D.	Canada
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Peterson, R	Canada
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A full address list for the participants is provided in Appendix 5.

2 TRENDS IN RECRUITMENT AND FISHERIES, CAUSES AND EFFECTS ON STOCK AND YIELD

2.1 Trends in Commercial Landings of American Eels

2.1.1 Reported elver catches

Canada: Commercial harvests of American eel elvers began in the Bay of Fundy and Atlantic coastal areas of Nova Scotia and New Brunswick (Scotia-Fundy area) in 1989 (Table 2.1.1.1). Landings steadily increased to a peak of 4,122 kg in 1997 and then, because of reduced market demand, declined to 478 kg in 1999 and 622 kg in 2000.

United States: An elver fishery occurred in Maine during the late 1970s and collapsed due to poor market conditions (Table 2.1.1.1). It continued at a low level until the early 1990s when Asian demand for elvers for aquaculture greatly increased. The Asian market collapsed in 1999, resulting in much reduced fishing effort in all areas. The collapse resulted from decreased demand for elvers of North American origin consequent to high catches of Japanese eel elvers and the production of market-sized cultured eels in excess of Asian demand. Several other Atlantic coastal states also developed elver fisheries during the 1990s, but no catch data are available (Jessop 1997).

Caribbean and Central America: The periodic reporting of “river eel” catches in Caribbean and Central American countries by FAO (Table 2.1.1.2) are believed to be glass eels/elvers caught for export. Information available in FAO fisheries databases suggests catches of as much as 49 t of eel in some recent years by some countries, at prices which suggest most of the catch must be glass eels. However, incidental but well documented records of an older date (Fernandez and Vasquez 1978) quantify 0.4 to 7 t of glass eels being caught in some rivers in Holguin Province in Cuba. This suggests that catches of glass eel/elver from the Caribbean and Central American countries might well be underreported by FAO, and probably comprise a large share of glass eel catches of American eel. A better understanding and better recording of eel catches in Caribbean and Central/ South American countries is urgently required.

2.1.2 Reported yellow and silver eel catches

North America: Total reported landings in North America (Canada and USA), 1950-1998 peaked at about 2,900 t in 1975 (Figure 2.1.2.1). Catches declined thereafter to about 1,000 t in 1997-1998, a level last seen in the mid 1950s and early 1960s. Over the entire period the average reported catch of each of Canada and the USA approximated 800 t.

Canada: Reported yellow and silver eel catches began in 1884 and peaked firstly at nearly 1,150 t in the 1930s and secondly at 1,359 t in the late 1960s to early 1980s (Figure 2.1.2.2; Table 2.1.2.1). Catches in 1999 are the lowest in 49 years. Catches from Ontario and Québec comprised the majority of Canadian landings until the 1960s when landings from the southern Gulf of St. Lawrence became significant (Figure 2.1.2.2). Catches in Newfoundland and the Scotia-Fundy portion of Nova Scotia and New Brunswick only became significant portions of total Canadian landings in the last two decades (Table 2.1.2.1).

Yellow and silver eel catches in the St. Lawrence River/ Lake Ontario system have steadily declined since 1992 from approximately 600 t to 200 t in 1997 (Figure 2.1.2.3; Table 2.1.2.1). A partial closure of the Lake Ontario fishery due to contaminants occurred in 1998 and 1999, which may account for a minor fraction of the decline in those years. A longer time series of yellow eel catches from Lake Ontario and the upper St. Lawrence River indicates an earlier catch cycle (Figure 2.1.2.4). Landings in the New Brunswick and Prince Edward Island portions of the Gulf of St. Lawrence have also exhibited a four-fold decline over the past decade (Figs. 2.1.2.5, 6; Table 2.1.2.1). However, landings from the Nova Scotia region of the Gulf of St. Lawrence (Figure 2.1.2.6; Table 2.1.2.1) and from Newfoundland (Figure 2.1.2.5; Table 2.1.2.1) show some variability but no clear trend. By contrast, an upward trend is clearly apparent in catches south of the Gulf of St. Lawrence, in the Canadian Atlantic / Bay of Fundy regions. Catches from the Atlantic and Bay of Fundy portions of Nova Scotia, and from the Bay of Fundy portion of New Brunswick have increased about threefold since the mid or late 1980s (Figure 2.1.2.6; Table 2.1.2.1).

United States: The United States fishery for American eels extends from Maine to the Gulf of Mexico (Table 2.1.2.2; Figs 2.1.2.1, 7). Different geographic regions (north, Figure 2.1.2.8, middle, Figure 2.1.2.9, and south Atlantic, Figure 2.1.2.10, and Gulf of Mexico, Figure 2.1.2.11) exhibit differing time trends in, and magnitudes of, their fisheries. This reflects the differing nature of their fisheries and regional stock abundance (Fahay 1978). Annual trends in reported eel catches by individual states are composed of three basic groups: catches continuing to decline below the long-term (1950-1998) mean, e.g., New Hampshire, Rhode Island, Connecticut, New York, South Carolina; catches increasing or remaining above the long-term mean, e.g., Maryland, Delaware; and catches that are below the long-term mean but have returned to values typical of those reported prior to the peak catches of the 1970s and early 1980s, e.g., Maine, Massachusetts, New Jersey, Virginia, North Carolina, Georgia, Florida (Jessop 1997) (Figure 2.1.2.7). Trends were assessed visually in relation to the long-term mean indicated for each state.

Caribbean and Central/South America: Little is known about the extent of yellow/silver eel fisheries and catches in Caribbean and Central and South American waters. Anecdotal reports indicate that occasional catches of some magnitude may occur in some areas. As noted in Section 2.1.1, the FAO reports of “river eel” catch are believed to be glass eel/ elver.

2.1.3 Reliability of reported catches

Canada: The elver fishery in the Scotia-Fundy area is closely regulated and of small size. Each fisher is required to provide daily catch and effort data. Independent dock-side monitoring was instituted in 1998. Illegal fishing at a low level has occasionally been reported and enforcement action taken. Consequently, misreported catches of elvers in Canada are believed minor.

The extent of the mis- or unreported catch of yellow/silver eels in Canadian provinces is unknown but often believed to be low. In Lake Ontario, the unreported eel catch is believed less than 5%. In Québec and the Scotia-Fundy portion of the Maritime Provinces, unreported catches are also believed low. For the St. Lawrence silver eel fishery, the extent of unreported eel catch was estimated at 8% in 1996 by comparing catches from index fishermen with official statistics. Sources of unreported catches might include recreational catches using a variety of gears, personal consumption, or local sale of commercially caught fish, native food fisheries, and incomplete data collection by statistical agencies. In the southern Gulf of St. Lawrence, a substantial portion of reported catch is subjectively estimated rather than tallied from purchase records, and substantial discrepencies between official figures and results of phone surveys have been reported. This suggests that reported landings for southern Gulf of St. Lawrence may contain substantial error.

United States: Mandatory reporting of catches in the Maine elver fishery was established only in 1998. Underreporting of catches occurred to an unknown, but possibly substantial, degree before 1998. The extent of underreporting of eel catches in American states is also unknown but is a major issue in some states, e.g., Maine, Maryland. Underreporting sometimes reaches 30% or more of the reported catch. Even when catch reporting is mandatory, misreporting may occur.

Caribbean and Central/ South America: The extent of eel fishing and reliability of catch data (presumably for elvers) in countries south of the United States is largely unknown.

2.2 Trends in Abundance Indices

2.2.1 Recruitment stages

The East River, Sheet Harbour (Nova Scotia) elver abundance series shows some variability over 10 years but no trend (Table 2.2.1.1; Figure 2.2.1.1). It represents the longest elver series available for this species. The East River, Chester (Nova Soctia) elver abundance index began in 1996 and is correlated with the East River, Sheet Habour. Index (n=4, r=0.998; p=0.002). Young yellow eels, recruiting to Lake Ontario at ages of more than three years, ascend the Moses-Saunders eel ladder on the upper St. Lawrence River. Eels have been counted at the ladder since 1974. Eel recruitment at the ladder has collapsed in recent years as indicated by the three order of magnitude decline in the number of recruits since 1986 (Table 2.2.1.2; Figure 2.2.1.2). Another abundance index series of recruiting young eels to the Petite Rivière de la Trinité, a small stream of the north shore of the Gulf of St. Lawrence (Québec), was carried out from 1982 to 1985, from 1993 to 1996, and reinstated in 1999 and 2000. These data show large inter-annual variability but no trend (Table 2.2.1.2; Figure 2.2.1.2). Finally, a short elver series was conducted in Little Sheepshead Creek (New Jersey) from 1989 to 1994, which suggests an upward trend in abundance in 1993 and 1994 (Table 2.2.1.2).

2.2.2 Yellow and silver eel stages

Three types of estimates of abundance trends of yellow and silver eels are available for the St. Lawrence River basin, one for waters of the State of New Hampshire, four for the Hudson River basin, and three for waters of the State of Virginia. Many of these time series were analyzed both with a nonparametric trend analysis, namely Kendall’s correlation tau as the test statistic on ranked data and by a resampling procedure. When available, probability values for the analysed data are given.

Lake Ontario trawl survey: A scientific trawl survey has been conducted in the Bay of Quinte on the north shore of Lake Ontario annually for the 28-year period from 1972 to 1999, except in 1989, for which year an estimate was used. The geometric mean number of yellow eels caught in ¼ nautical mile tows of a ¾-scale Yankee bottom trawl was calculated for each year (Table 2.2.2.1). The trend in this abundance index has been downward, although catches show considerable inter-annual variability (Figure 2.2.2.1). Catches in the last five years are an order of magnitude lower than in the first five years of the survey period.

Lake Ontario electrofishing survey: Records of catch per unit of effort were obtained for a commercial electrofishing operation for the 16-year period from 1984 to 1999. The mean number of eels caught per hour of electrofishing was calculated for each year (Table 2.2.2.1). Since 1989, the catch per unit of effort has declined significantly (p=0.0034) to less than 20% of the pre-1990 values (Figure 2.2.2.1).

Lower St. Lawrence weir silver eel survey: Large commercial weirs (interception nets) set perpendicular to the shoreline in the intertidal zone of the St. Lawrence estuary have been operated since the early 1900s. The fishery is prosecuted primarily in the 80 km extending downstream from about 120 km below Québec City. For the 21-year period from 1979 to 1999, the catch per unit of effort has been calculated as the kilograms of eels caught per meter of weir length (Table 2.2.2.1). The catch per unit of effort in the last five years has declined significantly (p=0.0015) to less than one-third of that of the first five years of the survey (Figure 2.2.2.1).

New Hampshire pot fishery survey: For 11 years in the period 1988 to 1999 (except 1989), catch per unit of effort was estimated for the commercial yellow-eel pot fishery in two to seven New Hampshire river basins (Table 2.2.2.1). The number off eels per pot hour (x10) increased from 1990 to 1995 and has decreased since (Figure 2.2.2.2). The shortness of the time series and the variability in fishing areas included in the survey makes interpretation problematic; there is no statistically significant trend.

Hudson River Utilities beach seine survey: For the 12-year period from 1985 to 1996, bi-weekly (June-October) scientific beach seine samples were taken in the brackish and tidal-freshwater portions of the Hudson River estuary. About 1,000 samples were taken each year with a 30.5 m beach seine. Annual catch per unit of effort was calculated as the total number of eels caught divided by the number of samples taken that year (Table 2.2.2.1). The catch per effort declined significantly over this period (p=0.0038) (Figure 2.2.2.3).

Hudson River Utilities fall shoal survey: For the same period and in the same area, bi-weekly samples were taken with a $1m^2$ Tucker trawl in the channel and a 3m beam trawl on the bottom in the channel and near shore. Annual catch per unit of effort was calculated as the number of eels caught divided by the volume of water sampled (Table 2.2.2.1). The catch per effort declined significantly over this period (p=0.0110) (Figure 2.2.2.3).

Hudson River Utilities impingement survey: At two power plants (Danskammer and Roseton) located near one another on the tidal freshwater portion of the Hudson River estuary, the total annual impingement of yellow and silver eels has been tabulated for the 23-year period from 1974 to 1996 (Table 2.2.2.1). Both series showed a decline over the period, with the downward trend more pronounced at Danskammer (Figure 2.2.2.3).

North Anna River electrofishing survey: Annual scientific electrofishing surveys were conducted in the Anna River, part of the York River basin, Virginia, for the 19-year period from 1981 to 1999. The catch per unit of effort is tabulated as mean number of eels caught per 70 m of electrofishing distance along the river (Table 2.2.2.1). This series shows an increasing but nonsignificant trend of abundance (Figure 2.2.2.4).

Potomac River commercial eel pot survey: For the 12-year period from 1988 to 1999, a catch per unit effort has been calculated from the commercial pot catches of yellow eels in the Potomac River estuary. The catch per unit of effort is tabulated as the number of eels caught divided by the number of pot-days fished (Table 2.2.2.1). There was a significant (p=0.0233) increase in catch per effort over this period (Figure 2.2.2.4).

Virginia Institute of Marine Science trawl survey: Annually during the 45-year period from 1955 to 1999, a scientific trawl survey has been conducted at several locations in the estuaries of the James, York, and Rappahannock Rivers of the Chesapeake Bay. A liner was added to the standard trawl in 1972, and a tickler chain was added in 1978. These changes undoubtedly altered the vulnerability of eels to the gear. Data are tabulated as the geometric mean number of eels >153 mm long per trawl (Table 2.2.2.1). Since the tickler chain was added, catch per effort increased for a few years, but it has declined since the mid-1980s (Figure 2.2.2.4).

Indices of abundance from a particular geographic area may not be independent of each other. Consequently, the common trend for each geographic area has been considered. In the upper St. Lawrence River and Lake Ontario, juvenile eel indices declined, no trend was found in New Hampshire, the Hudson River indices declined (one non-significantly), the Virginia North American River index showed no trend, and the Chesapeake Bay trawl survey indicated a decline. Only the Potomac River index showed an increasing trend.

2.3 Causes of Observed Trends in Recruitment

In Section 2.2, the available trends in recruitment have been described. In summary, a major decline in recruitment has been observed in the Upper St Lawrence and Ontario region, but in other regions, declines have not been observed but data are limited and usually short term. The decline in the St Lawrence region is strongly paralleled by a steep decline observed in the recruitment of the European eel (*Anguilla anguilla)* in almost all of mainland Europe since 1980. A number of potential explanations have been suggested (Castonguay *et al*. 1994). These include natural (below) and anthropogenic, (Sections 3.2 and 3.3) as well as continental and oceanic causes. No conclusive evidence has been brought forward so far. The following sections describe the hypotheses raised.

2.3.1 Oceanic factors

The basin-scale water circulation in the North Atlantic Ocean is subject to decadal time-scale variation. The influence of large spatial and temporal scale variation and decadal trends in circulation in the western North Atlantic on survival of leptocephali and recruitment of glass eels has not been determined at this time. Nevertheless, the potential for such an influence is considered below.

General trends in circulation can be inferred from atmospheric patterns and from Gulf Stream patterns. The North Atlantic Oscillation Index (NAOI) is the sea level atmospheric pressure at the Azores or at Lisbon, Portugal, minus the sea level atmospheric pressure at Reykjavik, Iceland. A winter time series from 1864-1999 of the NAOI, normalised by dividing by the standard deviation of the values, is available (http:/www.cgd.ucar.edu/cas/climind/nao_winter.html). The cumulative sum of the index reveals several trends (Figure 2.3.1.1). From 1864 to about 1900, little trend occurred. Between 1900 and 1925, the NAOI was generally high, resulting in a rising trend in cumulative sum. The NAOI fluctuated about the average until about 1955, whereupon the NAOI was generally low until 1970 (Figure 2.3.1.2). The NAOI again became generally high between 1970 and 1995.

High values of the NAOI indicate periods of stronger winds, greater surface-water mixing, and a reduced and more easterly path of the Gulf Stream and North Atlantic Current, and vice versa. Changes in transport during decades of high or low values of the NAOI could influence the delivery of leptocephali of the American eel, especially at the northern end of its geographic range.

A five-year fast Fourier transform was fitted to the time series of the NAOI to filter out the high frequency variation and to emphasise the fundamental long period of approximately eight years in the atmospheric-ocean interaction. There is a strong negative correlation between the smoothed values of the NAOI and recruitment of glass eels of the European eel to den Oever, Netherlands (Figs. 2.3.1.3,4). Similarly, there is a negative correlation of the NAOI and the abundance of juvenile American eels ascending the Moses-Saunders dam between New York and Ontario, when the abundance data are lagged by four years (Figure 2.3.1.3).

The position of the North Wall of the Gulf Stream since 1966, derived from aircraft and satellite observations, has been published (http://www.pml.ac.uk/gulfstream/inetdat.htm). A useful index is based on principal components analysis of the latitude of the North Wall at six longitudes in the western North Atlantic (NWI) (Taylor 1995; 1996). A high NWI indicates relatively high latitude for the North Wall, and vice versa. The cumulative sum of the NWI shows that the trend between 1970 and 1982 was for southerly positions of the North Wall and between 1982 and 1995 was for northerly positions (Figure 2.3.1.5). The NAOI and the NWI are correlated with the latter lagging by about two years.

High values of the NWI imply stronger transport by the Gulf Stream in the western North Atlantic (Kelly 1991), but also stronger recirculation in the western North Atlantic (Kelly and Watts 1994). Among other influences, trends in the NWI are associated with trends in zooplankton abundance, at least in the eastern North Atlantic (Taylor 1995). If similar trends in production occur in the western North Atlantic, they could influence survival of leptocephali at sea. The NAO influences hydrographic conditions in the Sargasso Sea, which could influence the location and timing of spawning of eels and transport of the resulting leptocephali.

2.3.2 Effects on continental life stages

2.3.2.1 Continental factors affecting the incoming recruitment

Glass eels: The recruitment of young eels to the continent is monitored just inside continental waters. All fisheries for glass eel or elvers are operated at the interface between fresh water and the sea. Therefore, it seems rather unlikely that continental factors have been influencing the abundance of incoming young of the year already at sea.

Young yellow eels: Recruitment to the upper St. Lawrence and Lake Ontario as monitored at the Moses-Saunders dam involves young eels, usually ranging in age from 3-14 years, after their metamorphosis from the leptocephalus stage. Over the past 18 years, eel passage has decreased by three orders of magnitude. It is unclear to what extent this immigration has been affected by the Beauharnois Dam 50 km downstream, a reduction of vessel lockage (by half) in the St. Lawrence Seaway system during the period, and in increase in the commercial harvest (doubled) of yellow eels in Lake St. Francis, immediately downstream. These factors may have contributed to the decline but cannot fully explain this virtual loss of recruitment. Just as important for this more distant stock, oceanic effects (Figs. 2.3.1.3, 4) and changes in spawning stock abundance may be involved. However, since the St. Lawrence River is one of the largest rivers in North America, the decline in juvenile immigration to the upper St. Lawrence River-Lake Ontario area and the consequent reduction in yellow eel abundance and silver eel escapement has resulted in a major loss of escapement of large, fecund spawners from the continent.

2.3.2.2 Continental factors affecting the fecundity of the spawning stock

Continental factors affecting older continental life stages all operate through a reduction of the total fecundity of the escaping spawning stock, either in quality or in quantity of the escaping spawners.

Reductions in the quality of spawners escaping:

Parasitism- The swimbladder parasite *Anguillicola crassus* was found in the American eel (Barse and Secor 1999) in 1997, but may have been present earlier. This parasite is indigenous in eastern Asia, where it occurs in the Japanese eel (*Anguilla japonica*). It has been found in European eel in Europe since the mid 1980s. It has been hypothesised to hamper the oceanic migration of the silver eel to the spawning area. For the European eel, the occurrence of this parasite does not match the time that this decline in recruitment occurred. For the American eel, the apparently recentariul of *Anguillicola crassus* would not yet have had any substantial effect on the spawner escapement.

Contamination- Man-made organochlorines are bio-accumulated in eel, but there is no evidence of major effects on survival. Declines in recruitment in the St Lawrence River (and in Europe) do not coincide with periods of maximum contamination by organochlorine compounds (Castonguay *et al*. 1994; Knights 1996). Furthermore, spawner escapement from uncontaminated areas is supposed to be substantial.

Reductions in the number of spawners escaping: A number of hypotheses have been raised concerning a potential reduction in productivity of continental waters in terms of the number of spawners escaping. This might include reductions in habitat areas or in the accessibility of habitats, and intentional (fisheries) or unintentional (hydro-power dams; see Section 3.2) reductions of the continental stock by numbers.

Habitat area- Eels and eel fisheries are found all over the Atlantic region of North America, but most intensively in areas of maximum human environmental impact, namely the coastal zone of the continent. Land reclamation, flood control, and drainage of marshland all have reduced the amount of habitat available to the eel (Section 3.2.2).

2.4 Summary/Conclusions

American eels are exploited to varying degrees in one or more life stages (elver, yellow and silver eel) throughout much of their range. Fisheries for elvers are limited to localised areas of Atlantic Canada, the northeastern USA and several Caribbean countries. Elver catch series are short, show no trend, and are affected by market conditions. Yellow and silver eel catches from the Lake Ontario / St. Lawrence River ecosystem as well as from the Gulf of St. Lawrence have steadily declined by a factor of about three in the past decade. In contrast, catches from Atlantic Nova Scotia and the Bay of Fundy have increased by a factor of three since the mid or late 1980s. Yellow and silver eel catches in the USA exhibit various trends, primarily negative, but no geographic pattern occurs there as opposed to the patterns observed in Canada. Incomplete or misreporting is a major problem in the USA, but less so in Canada.

The two major abundance series of recruitment show dramatically different trends. A 10-year long abundance index series of elvers from Nova Scotia shows no trend. However, a longer 27-year series of recruiting yellow eels to Lake Ontario at an eel ladder shows a 3 order of magnitude decline that started in 1986. Eleven abundance indices from scientific surveys are available for yellow and silver eels. Eight of the 11 time series observed declines in abundance of yellow and silver eels. Only one series showed a significant increase with time. However, it was noted that indices of abundance from within a particular geographic area may not necessarily be independent of each other and that on the basis the six geographic units that were represented: 1) three indices declined (St. Lawrence/ Lake of Ontario, Hudson River and Chesapeake Bay); 2) two showed no trend (the New Hampshire and Virginia rivers), and 3) one increased (Potomac River).

A major decline in recruitment to the St. Lawrence / Lake Ontario has been observed that paralleled a steep decline in *Anguilla anguilla* in Europe. However, there is no evidence of a recruitment decline elsewhere due to lack of data for the American eel, although declines in abundance indices of yellow and silver eels were noted for 8 of the 11 time series in the species' range. A number of potential explanations have been suggested for the St. Lawrence / Lake Ontario decline that includes anthropogenic continental causes as well as oceanic causes.

In conclusion, recruitment is down in the St. Lawrence / Lake Ontario, but the representativeness of this decline on the species as a whole is unknown. Further, the decline in yellow and silver eel abundance throughout the species' range most likely represents a decline in escapement. Historically, the St. Lawrence River likely made an important contribution to the spawning population because it is one of the largest watersheds available to the species (Castonguay *et al*. 1994) and it produces large fecund females. A decline there results in a major loss of escapement of fecund spawners from the continent.

Table 2.1.1.1. Reported catch of elvers (kg) in the Bay of Fundy New Brunswick, Atlantic coast of Nova Scotia and in the State of Maine.

Year	NB	NS	Total Canada	State of Maine
1977				10,000
1978				7,566
1989	0	26	26	
1990	132	42	174	
1991	65	0	65	
1992	227	0	227	
1993	534	179	713	
1994	650	924	1,574	3,352
1995	549	2,689	3,238	7,545
1996	449	2,414	2,863	4,633
1997	852	3,270	4,122	3,345
1998	501	1,547	2,048	6,527
1999	0	478	478	1,630
2000	0	622	622	

Note: little fishing activity occurred in 1999-2000 due to poor market conditions.

Table 2.1.1.2. Reported catches (t) of river eel in the Caribbean area, 1970-1997. Data are from FAO Fisheries Statistics. No catches were reported prior to 1975. It is believed that reported catches are *Anquilla rostrata* glass eel/elvers.

Year	Cuba	Dominican Republic	Mexico
1975			1
1976			7
1977			7
1978			
1979			
1980			
1981			
1982			
1983			
1984			
1985			
1986			
1987			
1988		1	
1989	1	1	
1990			
1991			
1992			
1993			
1994		49	
1995		44	43
1996			35
1997			19

Table 2.1.2.1. Reported catches (t) of American eels in Canada, by province and region, exclusive of elvers. USL-LO- upper St. Lawrence R. and L. Ontario; SLR (Silver)- St. Lawrence River silver eels (inc. in Total Québec); NB/NS (Gulf)- Gulf of St. Lawrence area of New Brunswick/ Nova Scotia; NB/NS (Total) provincial total catch, nominally the sum of Gulf and SF area catches; Gulf/SF Total- sum of NB-/NS-Gulf and NB-/NS- SF catches. Total Canada = sum of USL-LO, Total Québec, NB(Gulf), NB(SF), PEI, NS(Gulf), NS(SF), and NFLD.

Year	USL-LO	SLR (Silver)	Total Québec	NB (Gulf)	NB (SF)	NB (Total)	PEI	NS (Gulf)	NS (SF)	NS (Total)	Gulf Total	SF Total	NFLD	Total Canada
1884	2.52													2.5
1885	4.01													4.0
1886	8.73													8.7
1887	6.44													6.4
1888	4.14													4.1
1889	6.12													6.1
1890	8.42													8.4
1891	8.23													8.2
1892	19.62													19.6
1893	30.51													30.5
1894	35.15													35.2
1895	26.42													26.4
1896	32.31													32.3
1897	14.18													14.2
1898	18.72													18.7
1899	15.66													15.7
1900	18.18													18.2
1901	30.15													30.2
1902	29.39													29.4
1903	16.52													16.5
1904	20.52													20.5
1905	8.69													8.7
1906	8.28													8.3
1907	9.18													9.2
1908	10.08													10.1
1909	29.48													29.5
1910	47.25													47.3
1911	62.42													62.4
1912	101.43													101.4
1913	86.09													86.1
1914	134.96													135.0
1915	98.91													98.9
1916	64.26													64.3
1917	56.70			51.0			3.4	12.6			67.0			123.7
1918	61.38			61.8			23.9	13.1			98.8			160.2
1919	57.29			75.1			0.0	6.3			81.4			138.7
1920	41.36	56.1	282.3	24.2			8.2	10.7			43.1			366.8
1921	50.49	89.3	314.1	40.7			37.0	14.8			92.5			457.1
1922	66.11	20.7	454.5	14.0			9.5	7.5			31.0			551.6
1923	55.76	18.4	559.6	10.2			3.8	0.7			14.7			630.1
1924	53.91	50.9	540.6	10.0			35.6	7.5			53.1			647.6
1925	68.27	82.6	536.0	18.4			14.5	4.3			37.2			641.5
1926	51.8	113.8	960.1	5.4			8.7	5.7			19.8			1031.7
1927	48.33	72.1	615.5	1.4			5.9	3.5			10.8			674.6
1928	40.64	72.8	992.1	16.3			11.1	6.6			34.0			1066.7
1929	33.3	62.0	541.1	5.2			2.8	4.5			12.5			586.9

Table 2.1.2.1 cont'd

Year	USL-LO	SLR (Silver)	Total Québec	NB (Gulf)	NB (SF)	NB (Total)	PEI	NS (Gulf)	NS (SF)	NS (Total)	Gulf Total	SF Total	NFLD	Total Canada
1930	43.43	67.3	596.7	11.8			5.9	15.2			32.9			673.0
1931	32.58	65.3	785.7	18.8			4.8	11.9			35.5			853.8
1932	22.28	80.8	864.7	9.1			8.2	13.8			31.1			918.1
1933	28.44	99.7	1115.0	11.0			5.9	16.7			33.6			1177.0
1934	22.19	82.7	1027.1	11.3			5.1	5.8			22.2			1071.5
1935	26.82	83.9	1026.9	7.6			10.2	5.2			23.0			1076.7
1936	23.67	84.0	988.2	4.4			8.6	4.1			17.1			1029.0
1937	29.7	80.1	836.9	5.7			16.5	4.2			26.4			893.0
1938	19.04	81.9	850.2	9.4			9.8	9.7			28.9			898.1
1939	10.22	74.9	774.0	11.0			9.6	8.7			29.3			813.5
1940	14.49	27.2	399.3	4.8			21.5	10.6			36.9			450.7
1941	7.38	21.8	453.7	3.6			15.7	3.4			22.7			483.8
1942	7.07	23.4	469.9	12.5			7.0	4.8			24.3			501.3
1943	15.62	29.7	638.5	14.1			10.9	5.0			30.0			684.1
1944	17.91	24.8	293.6	13.9			6.3	6.9			27.1			338.6
1945	19.58	2.0	389.6	14.5			6.1	10.7			31.3			440.5
1946	15.62	5.2	323.1	29.1			6.5	16.7			52.3			391.0
1947	15.03	3.0	324.4	31.8		35	7.7	13.6		34	53.1			392.5
1948	17.82	13.3	229.1	29.0		29	29.0	8.7		29	66.7			313.6
1949	20.7	41.4	185.8	29.4		32	15.9	37.6		87	82.9			289.4
1950	12.92	41.6	300.6	22.2		38	10.5	23.6		42	56.3			369.8
1951	21.42	54.7	351.4	15.5		15	13.6	20.9		46	50.0			422.8
1952	29.21	58.0	395.4	15.8		25	14.2	11.9		48	41.9			466.5
1953	25.61	63.0	406.1	13.1		34	33.1	7.7		48	53.9			485.6
1954	35.1	67.8	352.9	33.1		43	16.5	6.4		58	56.0			444.0
1955	30.6	68.6	405.8	48.6		88	24.1	10.5		78	83.2			519.6
1956	18.64	82.7	395.5	10.5		13	17.8	14.6		63	42.9			457.0
1957	44.6	94.9	562.3	8.6		14	12.3	10.1		32	31.0			637.9
1958	53.12	133.4	479.1	14.5		22	18.7	14.1		53	47.3			579.5
1959	55.39	102.7	390.3	23.6		30	26.4	11.4		31	61.4			507.1
1960	49.65	209.0	466.7	30.9		45	31.9	23.6		45	86.4			602.8
1961	58.63	167.0	388.7	57.4		66	17.7	27.8		52	102.9			550.2
1962	48.83	185.1	386.8	81.9		90	13.1	26.4		51	121.4			557.0
1963	76.32	197.1	472.8	53.7		66	15.9	23.6		68	93.2			642.3
1964	101.57	200.5	450.9	56.4		66	34.2	18.8		64	109.4			661.9
1965	84.92	257.8	553.8	62.6		68	48.6	16.3		56	127.5			766.2
1966	64.39	243.1	504.0	99.2		119	32.8	15.0		61	147.0			715.4
1967	61.04	250.8	447.0	108.0		98	61.8	52.3		67	222.1			730.1
1968	77.82	269.9	511.2	150.6		134	130.7	246.6		57	527.9			1116.9
1969	76.07	329.7	529.6	214.2		256	194.5	314.3		62	723.0			1328.7
1970	65.63	251.5	314.0	294.7		295	239.9	274.7		73	809.3			1188.9
1971	75.62	257.2	315.2	319.4		325	351.4	291.6		101	962.4			1353.2
1972	122.09	187.9	317.0	272.8		288	272.8	203.5		62	749.1			1188.2
1973	84.74	210.3	309.9	220.4		237	157.2	28.0		48	405.6			800.2
1974	99.86	247.5	395.5	156.2		178	101.2	265.5		42	522.9			1018.3
1975	166.29	368.3	529.4	120.8		169	103.5	374.1		41	598.4			1294.1
1976	153.96	274.8	425.3	118.7		198	94.1	279.0		27	491.8			1071.1
1977	186.39	362.7	510.9	110.1		265	97.6	5.9		15	213.6			910.9

Table 2.1.2.1 cont'd

Year	USL-LO	SLR (Silver)	Total Québec	NB (Gulf)	NB (SF)	NB (Total)	PEI	NS (Gulf)	NS (SF)	NS (Total)	Gulf Total	SF Total	NFLD	Total Canada
1978	229.7	375.5	530.3	81.6		126	113.6	12.3		64	207.5		15.6	983.1
1979	221.53	344.3	510.4	102.4		223	111.0	12.6		32	226.0		23.4	981.3
1980	164.03	426.2	602.8	150.4	25	175	120.1	9.5	40	51	280.0	67	82.2	1196.0
1981	107.9	401.4	603.5	191.2	35	227	220.0	7.5	20	28	418.7	55	41.5	1226.6
1982	29.02	231.7	936.5	159.2	3	163	167.6	11.3	15	26	338.1	18	36.7	1358.3
1983	75.56	220.9	353.0	97.4	1	98	150.5	9.6	19	31	257.5	20	28.0	734.1
1984	122.4	281.6	413.7	122.4	3	125	164.6	8.9	8	17	295.9	11	14.0	857.0
1985	103.95	0.0	[a]	202.4	74	276	139.4	5.1	7	12	346.9	81	25.0	556.9
1986	116.1	320.0	504.4	230.2	54	284	226.0	15.6	6	20	471.8	60	26.6	1178.9
1987	102.9	280.9	428.1	171.6	49	220	149.9	13.2	15	28	334.7	64	30.6	960.3
1988	105.3	288.0	440.5	233.5	135	369	124.7	24.7	14	38	382.9	149	60.8	1138.5
1989	121.49	281.7	433.0	209.0	116	326	69.5	30.2	6	32	308.7	122	83.5	1068.7
1990	119.04	295.6	473.9	149.3	91	240	123.7	20.8	5	26	293.8	96	146.6	1129.3
1991	116.96	259.7	395.7	130.4	88	218	126.6	34.7	39	74	291.7	127	133.9	1065.3
1992	123.02	180.0	283.2	119.5	59	193	54.0	55.9	62	118	229.4	121	89.9	846.5
1993	104.96	203.8	330.5	88.2	116	204	73.9	89.1	71	160	251.2	187	116.1	989.8
1994	82.31	161.4	255.1	68.0	131	205	45.8	42.1	100	141	155.9	231	110.9	835.2
1995	62.17	142.7	278.0	60.0	114	140	34.3	16.2	118	123	110.5	232	85.4	768.1
1996	56.75	105.7	225.0	48.6	102	151	33.3	11.4	72	83	93.3	174	95.0	644.1
1997	43.38	99.9	202.0	34.6	111	147	44.0	17.1	64	81	95.7	175	72.0	588.1
1998	21.48	127.2	227.5	49.2	88	137	40.7	15.0	75	90	104.9	163	73.0	589.9
1999	20.52	93.1	167.0	38.4	79	117	52.0	9.0	67	78	99.4	146	55.0	487.9

[a]The catch of silver eel was not recorded in 1985.

Table 2.1.2.2. Reported catches (t) of American eels, by state, for the Atlantic coast and Gulf of Mexico of the United States, 1950-1998. Data obtained from the National Marine Fisheries Service web site. Regional zones are: North Atlantic – ME-CT, Mid-Atlantic – NY-VA, South Atlantic – NC-FL, Gulf – LA-TX.

	North Atlantic					Mid-Atlantic					South Atlantic						Gulf		
Year	ME	NH	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL.E	FL.W	FL.Tot	LA	TX	Total
1950	17.2		7.9	15.1	6.8	123	34.6	15.4	422.8	227.5	79.2			4.4	0.6	5			954.5
1951	24.0		11.2	15.2	5.8	165.3	19.5	2.4	370.1	192.4	14.8			7.2	0.3	7.5			828.2
1952	19.1		11.9	6.9	8.3	70.1	22.4	15.5	381.6	167.1	17.5			5.5		5.5			725.9
1953	18.5		11.3	14.8	11.4	65	23.4	18.8	302.2	145	23.8		0.8	3.1	1.3	4.4			639.4
1954	5.2		9.8	6.9	11.4	81.1	30.8	16.4	165.7	190.5	16.8		0.8	2	3.9	5.9			541.3
1955	14.8	2.7	10.2	8.5	5.9	112.7	42.2	4.9	203	193	20.5			2.6	2.3	4.9			623.3
1956	13.3	2.3	7	9.4	8.5	106.9	26.7	6.8	211.6	203.3	51.3		0.2	2.3	2.4	4.7			652.0
1957	8.9	4.1	4.5	4.8	11.4	92.5	34.7	17.4	192.6	155.7	28.6		3	3.5	0.2	3.7			561.9
1958	9.7	3.4	8.3	9.4	9.4	122.3	28.3	11.7	182.2	190.3	39.4		0.1	3	0.2	3.3			617.8
1959	7.6	2.3	6	11.7	7.4	107.9	28.1	12	126.5	238.6	45		0.6						593.7
1960	13.8	2.7	16.2	19.6	8.5	103.4	18.8	2.9	88.5	87.2	29.9		0.4						391.9
1961	14.5	2.3	8.9	20.4	6	96.8	13.8	2.5	72.3	102	25.7		0.7						365.9
1962	16.1	2.9	7.3	15	8.1	58.7	10.1	4.3	51.8	96.3	19.6		0.1						290.3
1963	16.9	2.3	11	16.3	6.9	91.7	10.8	5.4	60.3	199.9	17.5		0.5						439.5
1964	10.4	2.3	8	14.2	8.2	78.8	35.7	5.4	84.4	142.3	24		2.5	55.4		55.4			471.6
1965	23.6	2.3	9.4	8.5	5.3	120.3	41.5	15.4	88.4	336.6	18.1		2.1	31.8	5.7	37.4			708.9
1966	22.1	3.2	11.2	11.3	3.9	77.2	65.2	14.5	100.8	212.7	24.7	18.7	0.4	13.8		13.8			579.7
1967	22.1	3.2	18.1	14.3	6.4	66.8	80.2	14.7	124.3	313.3	10.5	34.6	1.9	12.3	1.8	14.1			724.5
1968	29.7	16.4	20.5	17.6	19.1	65.7	53	16	120.2	321.9	11.1	55.2	0.7	21.6	0.4	22			769.1
1969	17.2	2.1	22.2	21	7.9	78.6	112.5	20	141.9	345.6	8	42.6		26.9	2.5	29.4			849.0
1970	17.1	2.5	25.6	16.6	22.5	62.7	95	26.4	131	546.5	7	10	2.4	13.6		13.6			978.9
1971	24.7	3.2	34.7	17.6	19.9	73.8	104.6	45.2	106.2	554.7	75.8	25.6	3	17.4	2.4	19.8			1109.0
1972	31.8	2.4	25.1	10.3	21.7	67.5	118.9	20.4	104.3	222.9	35.1	19.1	4.8	27.7		27.7			712.0
1973	34.5	2.5	17.9	8	12.1	51.6	104.7	27.4	81.8	115.5	60.6	31.9	5.1	37.1		37.1			590.7
1974	36.1	2.4	79.9	9.7	5.1	43.2	98.1	30.6	65.9	659.1	205	6.8	3.5	142.2		142.2			1388.0
1975	70.2	2.5	226.3	10	19.1	46.1	100.5	29.2	93	586.9	107.7	13.5	4.3	297.7		297.7			1607.0
1976	86.6	2.8	138.2	8.9	16.1	55.2	92.3	36.7	74.9	257.2	231.3	7.9	2	105.9	0.3	106.1			1116.0
1977	79.7	2.5	143.2	10.6	7.5	42.8	56.9	43.5	82.6	162.7	117.2	6.2	1.1	196.5		196.5			953.0
1978	60.6	2.0	150.4	11.9	11.5	48.2	53.9	85.3	93.5	527.7	315.5		1.1	241.7		241.7			1603.0
1979	50.4	1.9	135.8	10.2	12.3	44	52.8	85.3	121.7	544.6	433	4.5	3.9	144.7		144.7			1645.0
1980	47.9	2.7	114.7	10	10.9	209	38.1	60.3	146.2	193.2	435.5		45.1	51.7	2.9	54.7			1368.0
1981	25.0	3.0	97	8.2	10	154.9	53.1	90.4	330	342.1	197.8		5.8	51.6	0.5	52.1			1369.0
1982	20.5	3.2	60.1	4.9	8.8	83.2	109.9	61.9	38.3	323.9	215.7		16.6	30.4		30.4	3.5		980.9
1983	5.4	1.7	27.7	4.8	0.9	26.4	136	47.7	41.7	313.3	183.3			0.1	0.9	1	9		798.9
1984		1.3	14.9	2.8	3.4	48.2	242	56.4	49.7	356.7	320.4				0.7	0.7	2.7	0.1	1099.0
1985	10.9	1.0	11.6	3.9	2.1	53.7	153	60.3	39	359	101.7				1.2	1.2	11.5		808.9

Table 2.1.2.2 cont'd

	North Atlantic					Mid-Atlantic						South Atlantic					Gulf		
Year	ME	NH	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL.E	FL.W	FL.Tot	LA	TX	Total
1986	7.6	0.4	11.5	1.2	5.2	63.8	133.5	59.1	50.6	333.6	153.5			1.7	4.2	5.8		0.04	825.8
1987		0.2	11.2	0.5	11.2	28.8	86.8	43.3	56.3	338.5	58	0.02							634.8
1988		0.1	11.7	1.8	19.1	14.6	87	42.6	63.5	299.4	26		0.7	0.4	5.5	5.9	1.1	0.01	573.5
1989	12.7		13.6	0.9	9.6	20.2	87.9	52.5	149.2	237.2	69.2		2.5	0.1	3.5	3.6	0.4		659.5
1990	30.0		12.6		6	18.9	61.1	117.5	125	124.7	25.6			0.5	1.6	2.1			523.5
1991	8.3		10.6		4.4	20.2	98.4	116.2	176	219.1	5.5		0.7	0.2	2.8	3.1	0.02		662.5
1992	8.0	0.1	16.2		6.3	26.8	84.8	31.7	122	280.4	8			0.4	0.5	0.9			585.2
1993	6.6	0.6	12.6		4.5	19.3	88.2	59.9	180.4	274.1	14.8			0.8	0.6	1.4			662.4
1994	24.1					6.9	76.2	97.5	237.3	193.9	43.5			0.5	0.1	0.6			680.
1995	23.7		0.01		5.8	0.2	66.1	73.1	180.4	144.2	77		0.2						570.7
1996	4.6		0.01	0.1	8.3	0.4	105.1		186.7	276.3	64.2								645.7
1997	21.1		0.1			0	52.9		187.3	94.4	58.4								414.2
1998	15.9	0.2			2.5	0.2	42.8	59.6	212.1	86.5	41.3								461.1

Table 2.2.1.1 Annual estimates, with 95% confidence intervals (CI), of the run of American eel elvers to the East River, Sheet Harbour, and the East River, Chester, Nova Scotia.

Site	Year	Estimate	95% CI	Site	Estimate	95% CI
East River	1989	10,700[a]				
Sheet Harbour	1990	218,300				
	1991	376,000				
	1992	219,200				
	1993	134,100				
	1994	309,900	± 10,900			
	1995	101,500	± 1,600			
	1996	336,500	± 10,100	East River	1,138,100	± 24,200
	1997	467,400	± 7,000	Chester	1,419,000	± 52,100
	1998	109,200	± 2,000		432,400	± 8,200
	1999	134,600	± 600		441,700	± 9,800

[a]The run size was greatly underestimated due to operational problems.

Table 2.2.1.2. Recruitment indices for American eels. Eel ladder index is number of eels (ages 3-14) passed per day during the 31-day peak period at the ladder at the Moses-Saunders Dam. Juvenile eel counts (yearlings and 2-year olds) at Petite Rivière de la Trinité, mid-June to August, north shore, St. Lawrence River. Elver counts East River are total numbers (x10,000) caught. Glass eel counts on Little Sheepshead Creek are numbers dip-netted per m^3. Virginia index (VIMS) is catch per trawl with some modifications, including a liner added in 1972 and a chain tickler in 1978.

	St. Lawrence River system		Nova Scotia	New Jersey	Virginia
Year	Eel ladder Upper St. Lawrence (juveniles)	Petite rivière de la Trinité (juveniles)	East River Sheet Harbour (elvers)	Little Sheepshead Cr. (glass)	Virginia Inst. Marine Sci. (<153 mm)
1955					0.414
1956					0.047
1957					0.000
1958					0.000
1959					0.000
1960					0.000
1961					0.000
1962					0.000
1963					0.000
1964					0.110
1965					0.072
1966					0.008
1967					0.052
1968					0.114
1969					0.504
1970					0.015
1971					0.048
1972					0.017
1973					0.049
1974	7934				0.039
1975	14403				0.082
1976	10363				0.000
1977	20013				0.045
1978	16448				0.023
1979	18977				0.652
1980	9046				0.571
1981	13796				0.205
1982	27489	4576			0.133
1983	26426	4389			0.748
1984	15051	1046			0.764
1985	18510	1117			0.070
1986	5380				0.324
1987	9276				0.634
1988	5442				0.000
1989	5795			18.1	0.251
1990	3096		21.8	20.8	0.608
1991	1226		37.6	17.2	0.261
1992	277		21.9	17.2	0.752
1993	232	3681	13.4	23.6	0.318
1994	4998	763	31	32.4	0.081
1995	671	4047	10.2		0.005
1996	405	5547	33.7		0.014
1997	144		46.7		0.082
1998	57		10.9		0.020
1999	27	933	13.4		0.002

Table 2.2.2.1. Indices of abundance of yellow and silver American eels. All indices refer to yellow eels except for the impingement ones, which are yellow and silver combined, and the lower St. Lawrence River weir, which is exclusively silver eels. The Lake Ontario trawl index is number per ¼-nautical-mile, Bay of Quinte, and the Lake Ontario electrofishing index is number per electrofishing hour in the vicinity of Main Duck Island. Lower St. Lawrence River eel catch is kg per m of leader. New Hampshire eel pot index is lb(x10) per pot hour. The beach seine survey is number of eels caught per year divided by number of sampling periods. The fall shoal survey is the number of eels caught per trawl divided by the volume of water sampled. Impingement indices are total annual catch. The North Anna River index is the number of eels per 70 m of electrofishing (updated data file NA00x56B courtesy of N, Wooding, Virginia Power, Richmond, VA). The Potomac River eel pot is the summed annual catch divided by pot days. The Virginia index (VIMS) is mean catch per trawl haul.

	St. Lawrence River system				New York, Hudson River				Virginia		
							Impingement				
Year	Lake Ontario trawls	L. Ont. electro-fishing	Lower St. Lawrence weir	New Hampshire commercial eel pot	Beach seine survey	Fall shoal survey	Roseton	Dans-kammer	N. Anna R. electro-fishing	Potomac R. commercial eel pot	VA Inst. Mar. Sci. (>153 mm)
1955											6.55
1956											1.95
1957											0.16
1958											2.12
1959											0.60
1960											0.18
1961											1.88
1962											1.21
1963											0.80
1964											0.82
1965											0.26
1966											0.39
1967											0.77
1968											1.46
1969											1.04
1970											0.21
1971											1.23

Table 2.2.2.1 cont'd

	St. Lawrence River system				New York, Hudson River				Virginia		
							Impingement				
Year	Lake Ontario trawls	L. Ont. electro-fishing	Lower St. Lawrence weir	Hampshire commercial eel pot	BeachFall seine survey	shoal survey	Roseton	Dans-kammer	N. Anna R. electro-fishing	Potomac R. commercial eel pot	VA Inst. Mar. Sci. (>153 mm)
1972	1.873										0.63
1973	1.620						4.2				0.96
1974	0.997						20.7	119.6			0.40
1975	1.543						135.9	94.4			0.87
1976	1.286						92.6	231.9			0.53
1977	1.064						151.8	253.7			1.13
1978	0.417						63.3	122.5			0.98
1979	0.767		8.25				63.5	103.1			1.98
1980	0.252		10.08				64.0	186.2			4.19
1981	1.530		10.02				62.8	144.6	6.50		2.30
1982	1.884		18.15				23.1	173.1	6.25		2.36
1983	0.557		12.14				42.7	219.8	4.50		9.29
1984	0.330	85.6	7.66				17.2	150.2	7.00		5.66
1985	0.778	63.1	7.42		0.32	1.04	16.9	139.3	7.25		8.11
1986	0.865	82.9	6.79		0.16	1.39	11.8	107.2	4.00		4.56
1987	1.552	89.0	5.61		0.11	1.15	37.1	189.5	9.75		3.14
1988	0.299	68.8	5.52	0.58	0.14	1.24	40.6	110.9	4.00	1.13	1.32
1989	0.952	93.0	5.62		0.10	0.86	19.8	84.2	10.75	1.14	7.47
1990	0.356	64.1	7.05	0.12	0.08	0.20	41.1	91.6	9.00	1.05	4.51
1991	0.454	38.5	5.84	0.24	0.21	0.59	50.4	87.4	7.00	0.98	2.01
1992	0.584	44.5	3.78	0.39	0.01	0.01	36.4	65.3	5.00	1.62	7.01
1993	0.434	22.7	4.36	0.38	0.10	0.84	19.7	59.8	4.00	1.43	2.96
1994	1.157	30.0	3.57	0.51	0.09	0.98	22.6	46.2	2.75	1.05	2.14
1995	0.091	10.5	3.14	1.21	0.04	0.12	94.9	95.0	7.25	1.69	2.32
1996	0.356	14.9	3.58	0.59	0.01	0.01	27.3	62.1	15.50	1.72	2.55
1997	0.085	7.3	3.22	0.34					11.00	1.71	2.17
1998	0.123	12.9	4.25	0.10					10.25	1.76	1.97
1999	0.074	21.6	4.02	0.06					11.75	1.52	1.30

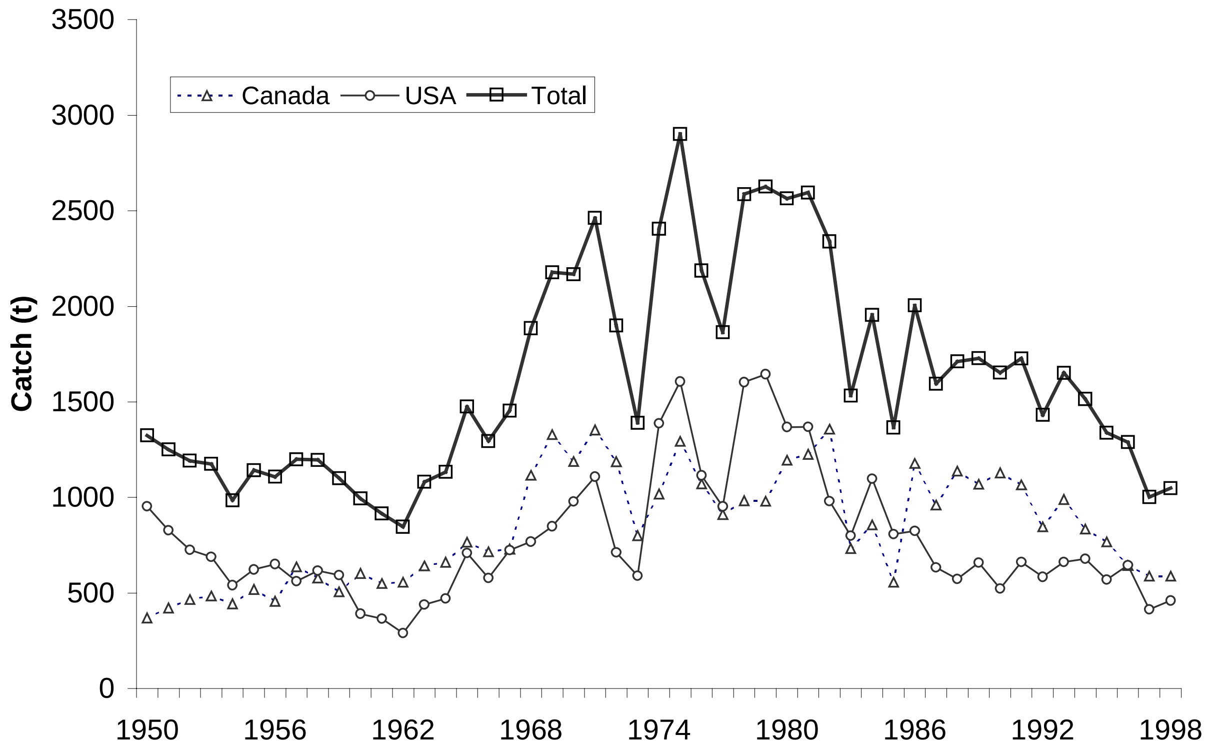


Figure 2.1.2.1. Reported catches of American eel (yellow and silver) by Canada and the United States, with a combined North American total, 1950-1998.

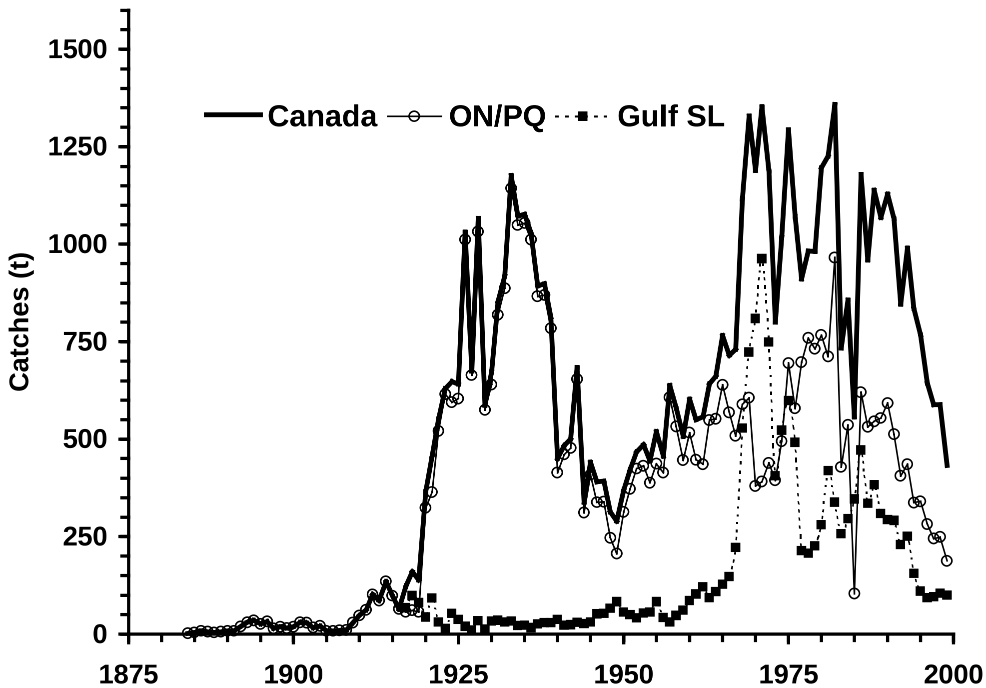


Figure2.1.2.2 Reported catches (t) of yellow and silver American eels from southern Gulf of St. Lawrence, (Gulf SL: Prince Edward Island, and portions of New Brunswick, and Nova Scotia), from Ontario and Quebec (ON/PQ) and from all of Canada, 1884-1999 (data in table 2.1.2.1).

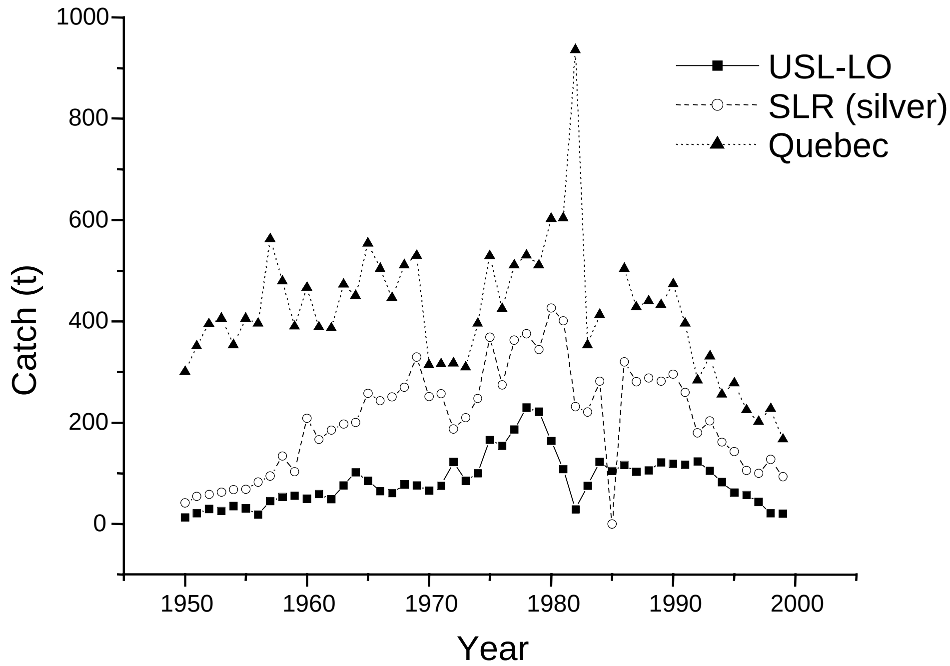


Figure 2.1.2.3 Reported catches of American eels in the upper St. Lawrence River-Lake Ontario (USL-LO), silver eels in Québec and total yellow/silver eels in Québec, 1950-1999.

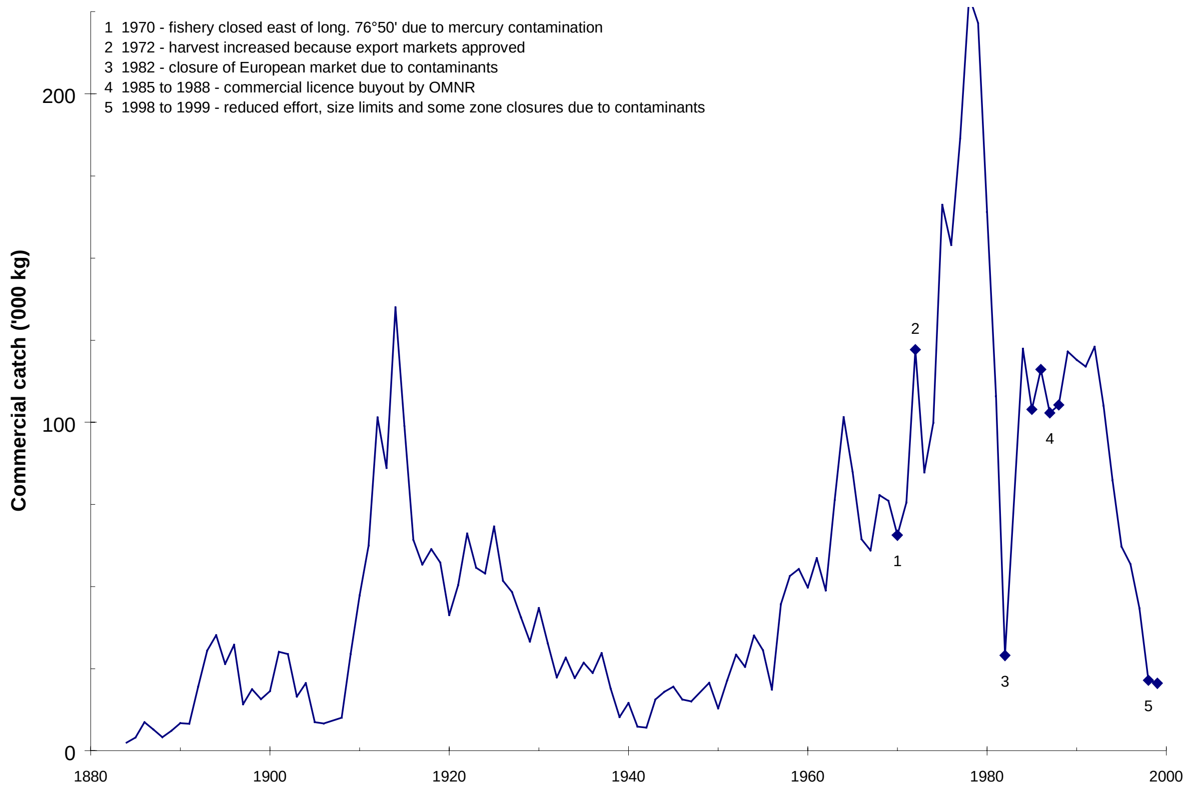


Figure 2.1.2.4. Commercial catch of American eels for all statistical districts in the Ontario waters of Lake Ontario and the upper Saint Lawrence River, 1884-1999. Major events that could affect the fishery and catch are indicated.

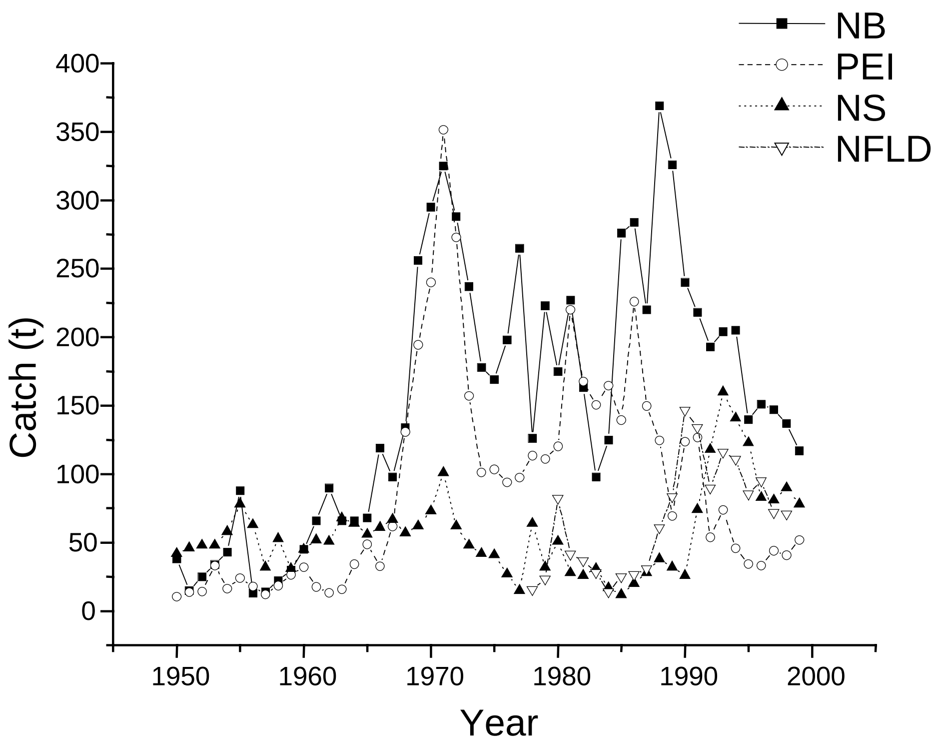


Figure 2.1.2.5. Reported catches of American eels, by province, in Atlantic Canada, 1950-1999. The silver eel catch was not recorded in 1985.

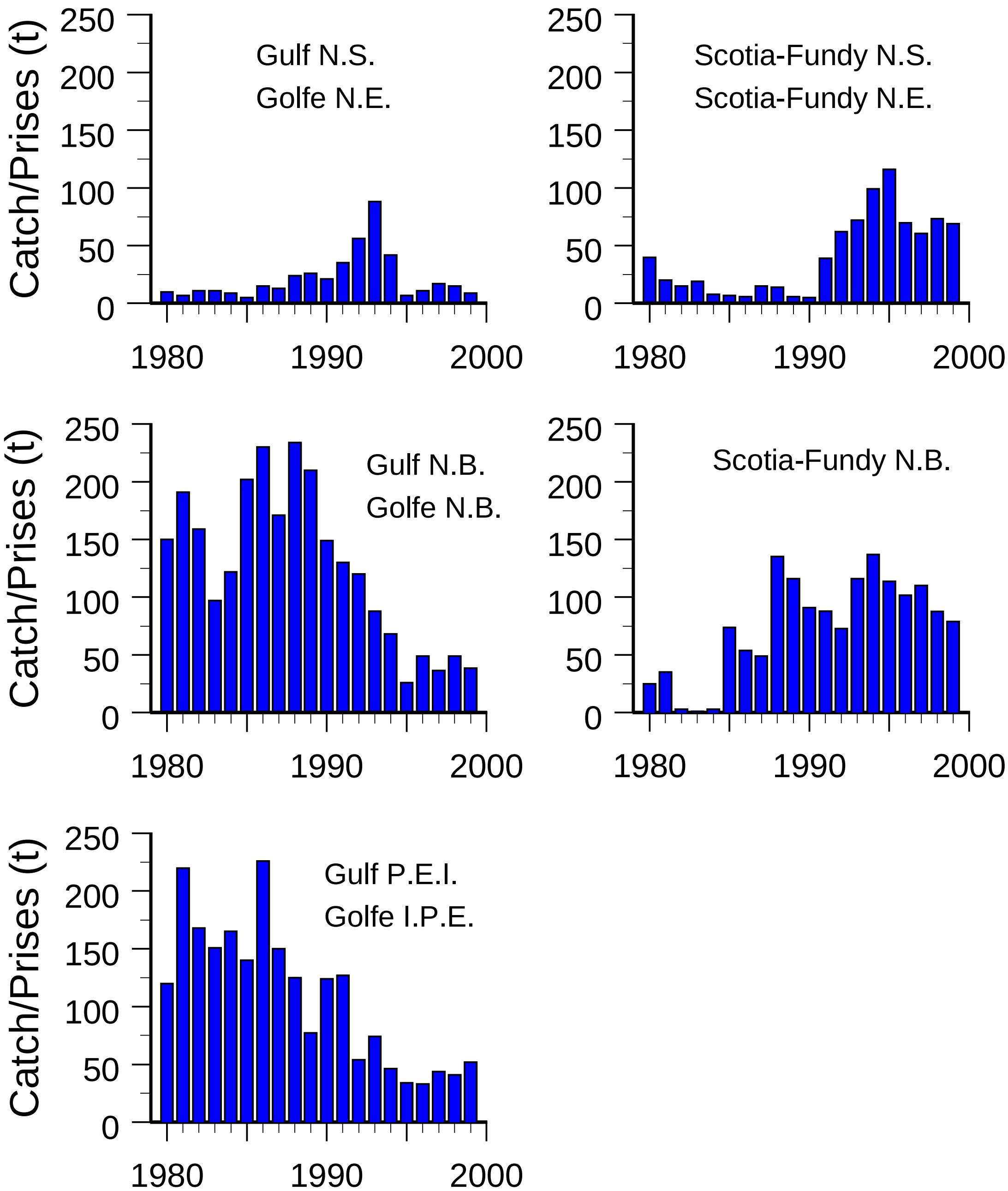


Figure 2.1.2.6. Annual catches (t) of American eels in the Gulf and Scotia-Fundy areas of the Maritime Provinces, 1980-1999.

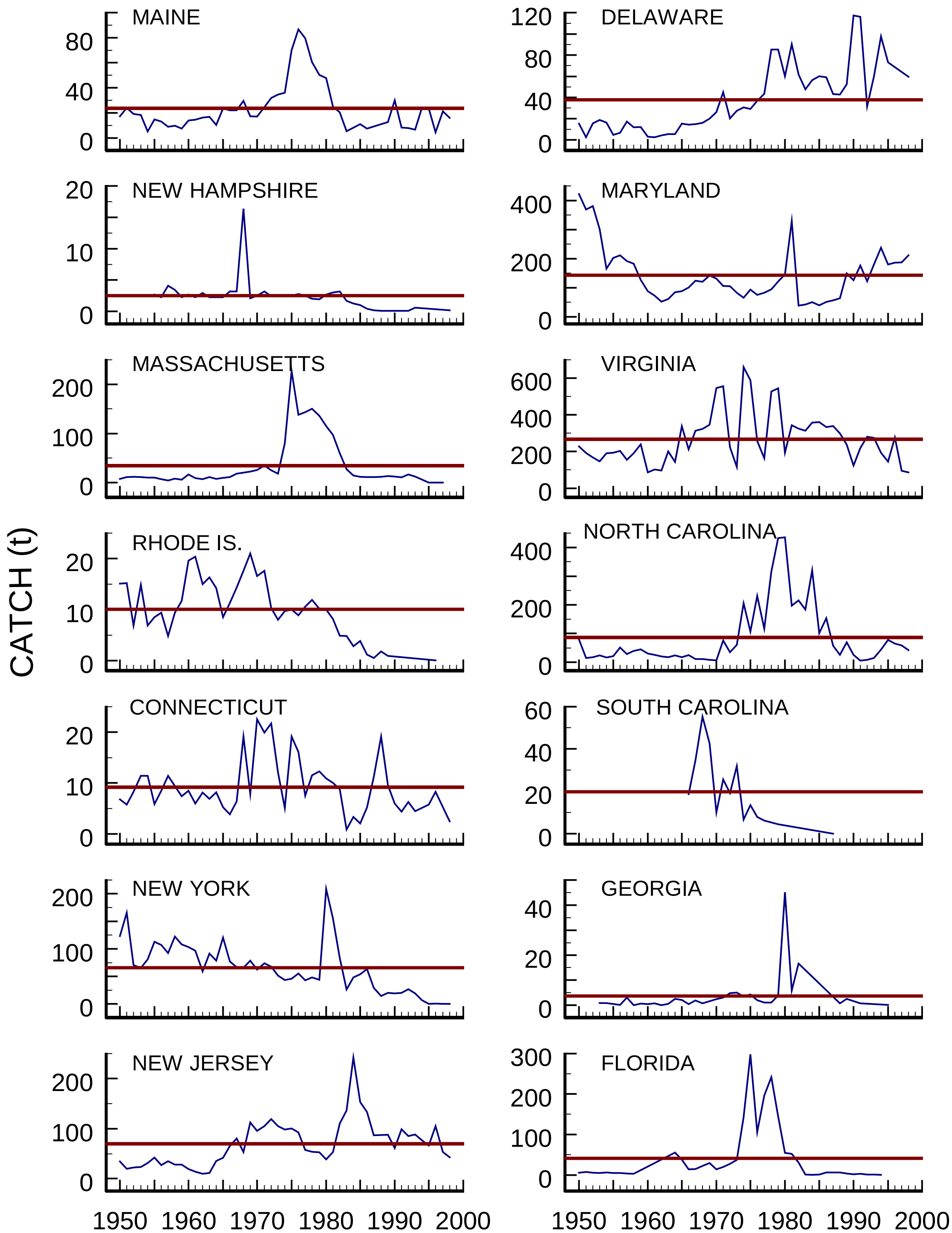


Figure 2.1.2.7. Annual reported catches of American eels, by state, for the Atlantic coast, 1950-1998. The horizontal line in each panel is the long-term mean catch for that state.

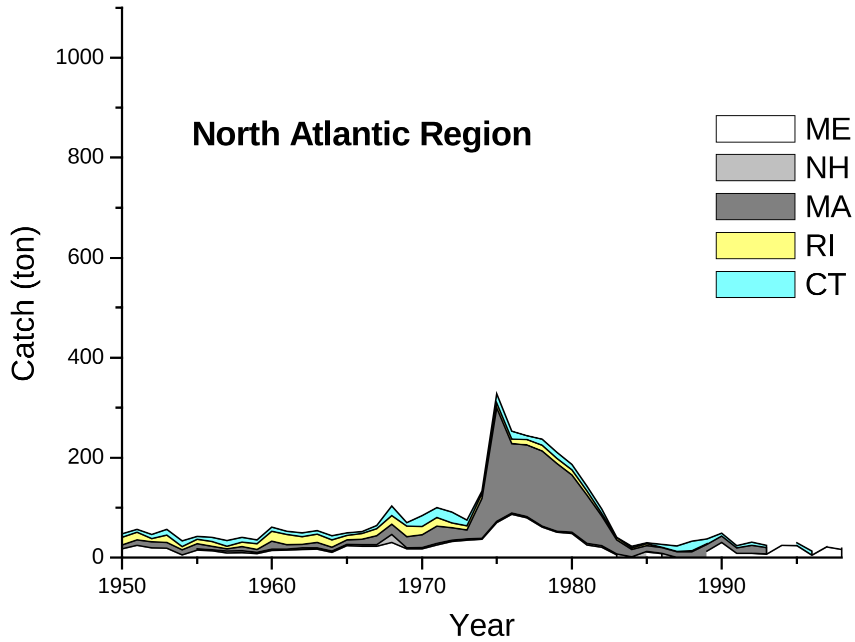


Figure 2.1.2.8. Reported catches of American eels in the North Atlantic region of the Atlantic coast of the United States.

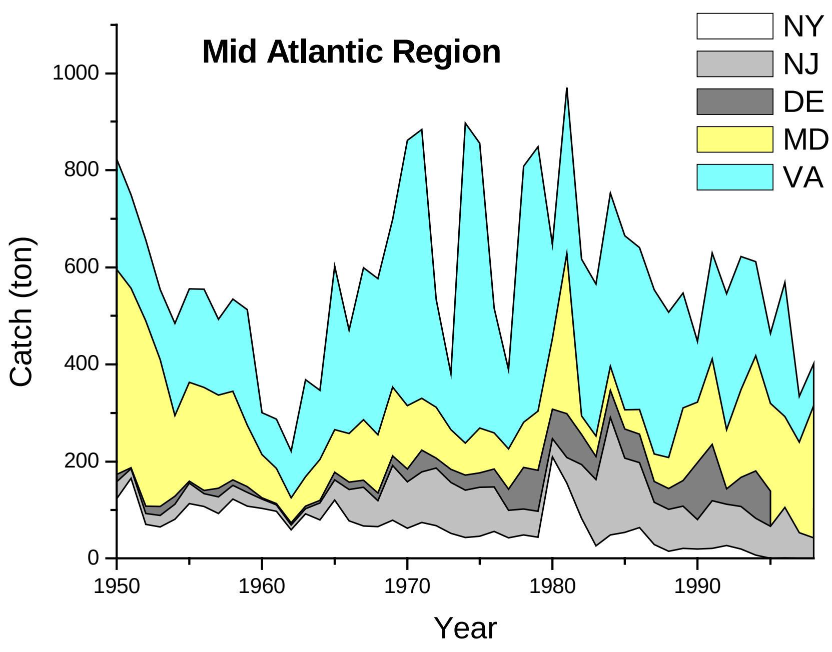


Figure 2.1.2.9. Reported catches of American eels in the Mid Atlantic region of the Atlantic coast of the United States.

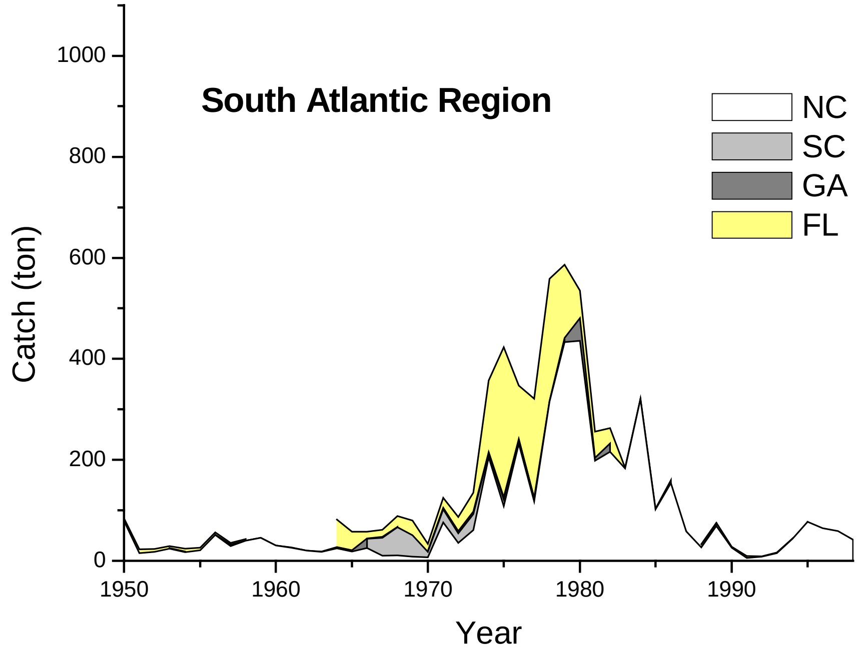


Figure 2.1.2.10. Reported catches of American eels in the South Atlantic region of the Atlantic coast of the United States.

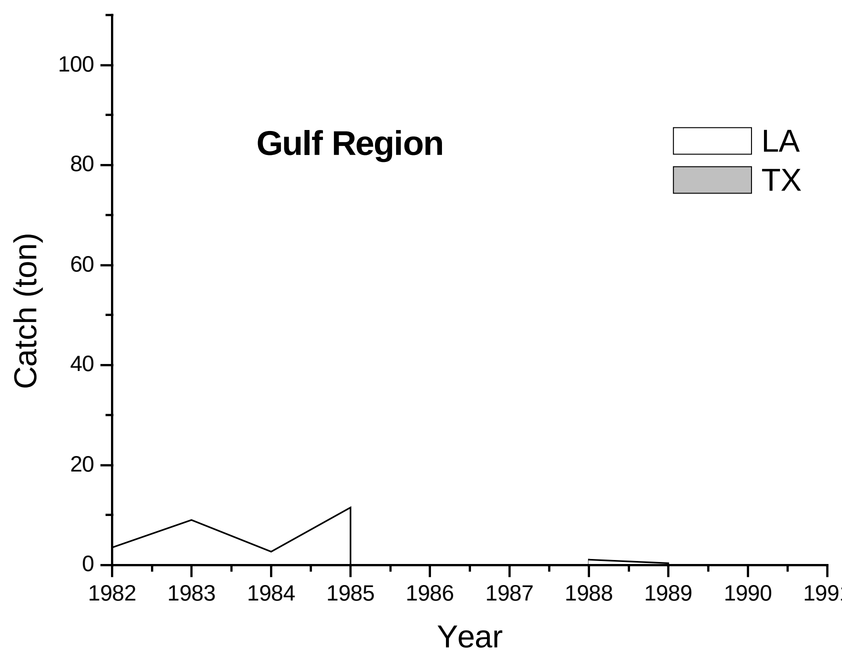


Figure 2.1.2.11. Reported catches of American eels in the Gulf of Mexico region of the Atlantic coast of the United States.

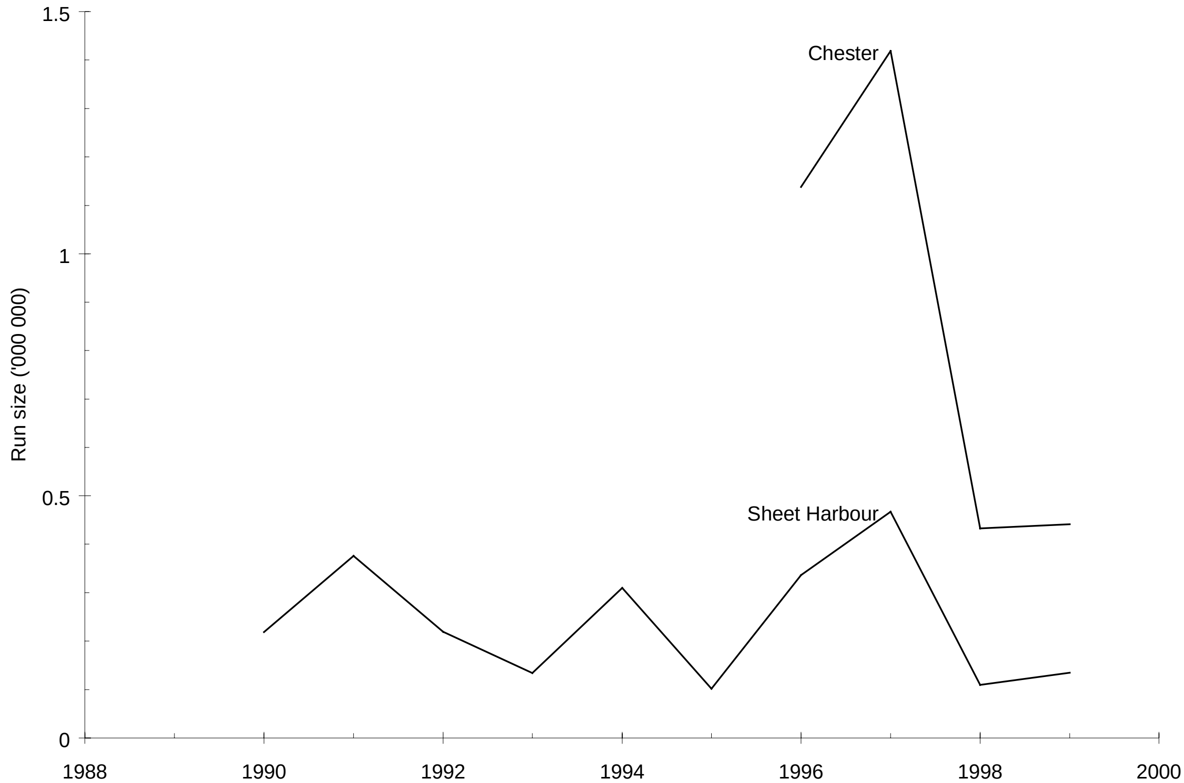


Figure 2.2.1.1. Annual run size of American eel elvers to the East River, Sheet Harbour, and the East River, Chester, Nova Scotia, 1990-1999.

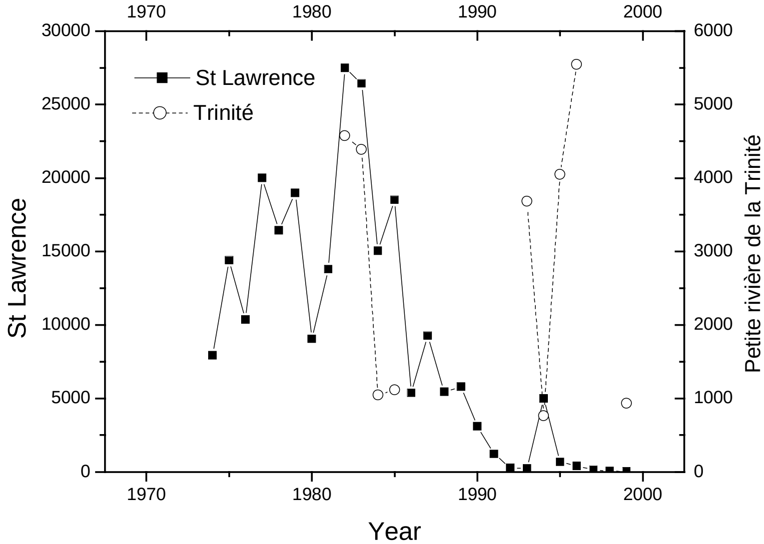


Figure 2.2.1.2. Annual indices of abundance of juvenile American eels from sites in the upper (Moses-Saunders eel ladder) and northern (Petite Rivière de la Trinité) parts of the Gulf of St. Lawrence.

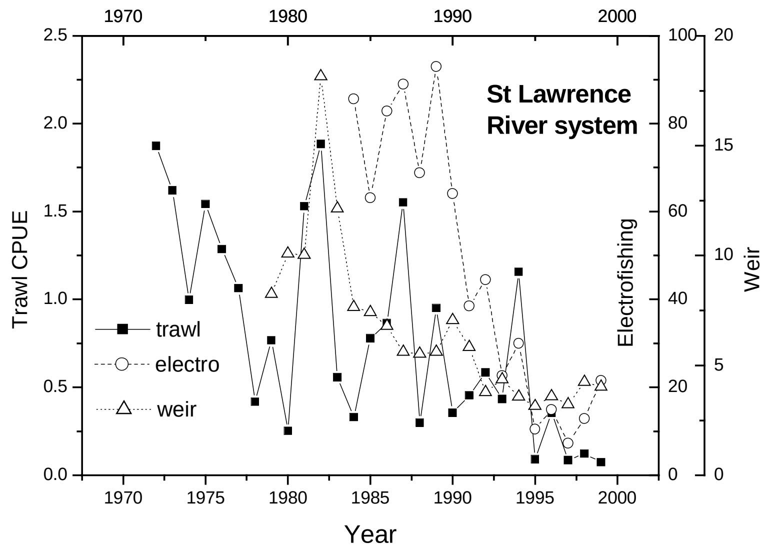


Figure 2.2.2.1. Annual indices of the abundance of American eels (yellow eels in the Lake Ontario trawl and Lake Ontario electrofishing surveys and silver eels in the St. Lawrence River weir survey) in the St. Lawrence river system.

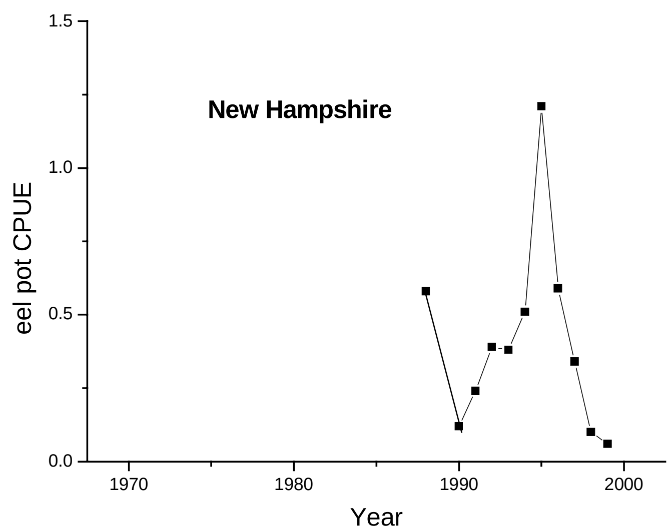


Figure 2.2.2.2. Index of yellow eel abundance (CPUE x 10 lb/h) from New Hampshire eel pot fishery.

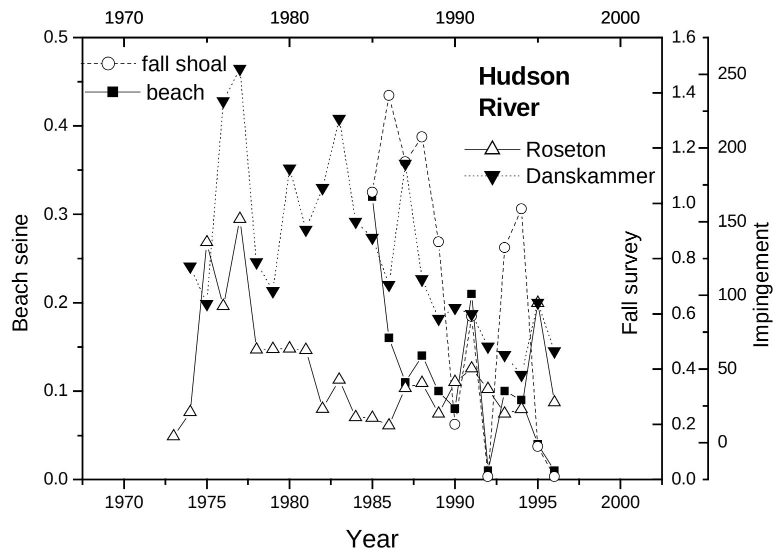


Figure 2.2.2.3. Indices of yellow eel abundance (eel impinged) at power station cooling water intakes at two Hudson River sites and of fall shoal and beach seine surveys in the lower Hudson River.

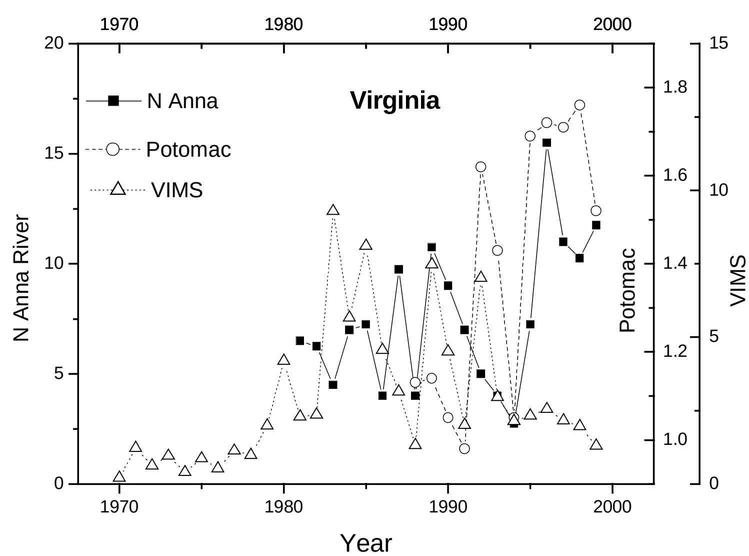


Figure 2.2.2.4. Annual indices of yellow eel abundance caught by trawl survey in Chesapeake Bay, Virginia, by electrofishing survey in the North Anna River, Virginia, and by commercial eel pot survey in the Potomac River, Virginia/Maryland.

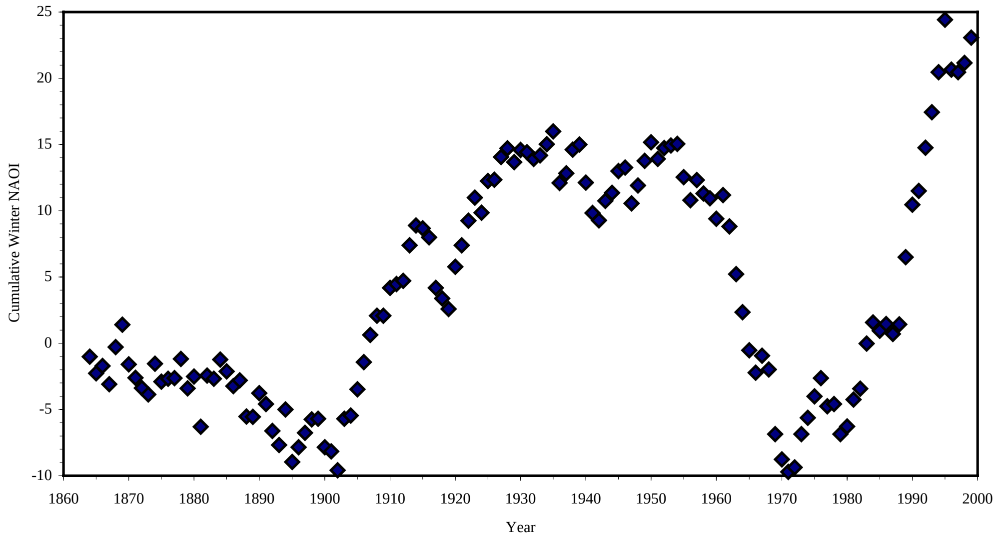


Figure 2.3.1.1. Cumulative sum of the normalized December-March index of the North Atlantic Oscillation from 1864 to 1999.

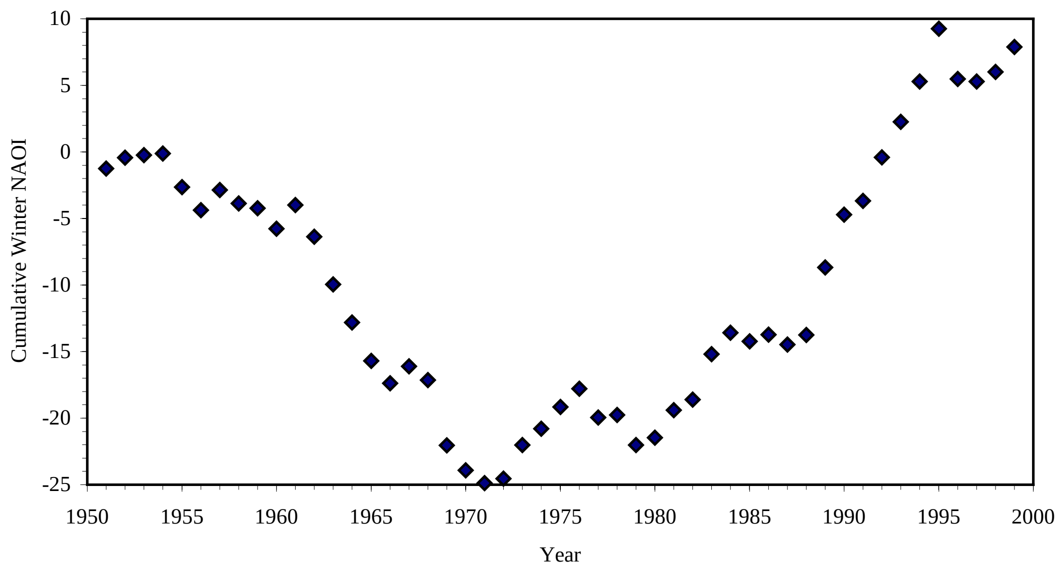


Figure 2.3.1.2. Cumulative sum of the normalised December-March index of the North Atlantic Oscillation from 1951 to 1999.

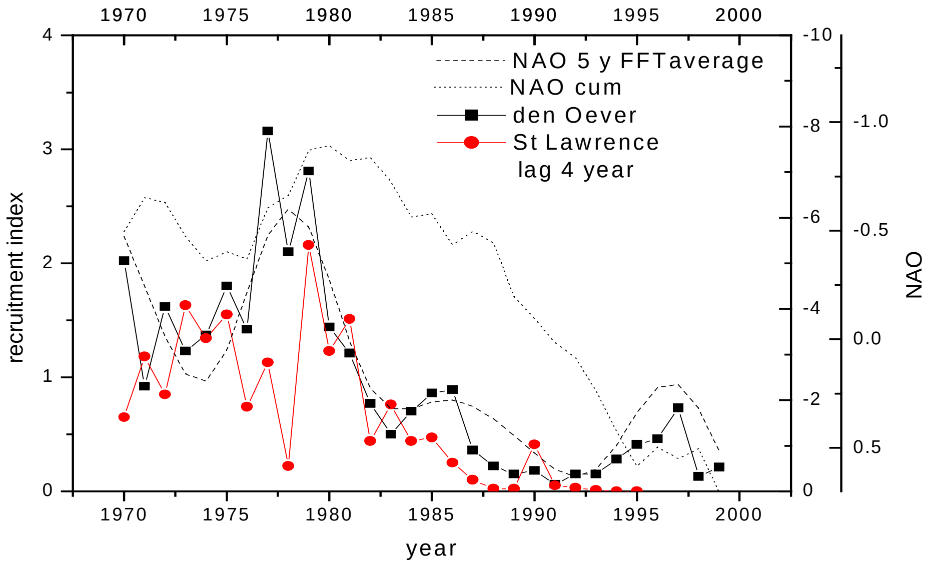


Figure 2.3.1.3. Recruitment indexes for glass eels of the European eel at den Oever, Netherlands, and for juvenile American eels at the Moses-Saunders dam on the St. Lawrence River, and the smoothed averages and cumulative sums of the North Atlantic Oscillation Index, 1970-1998.

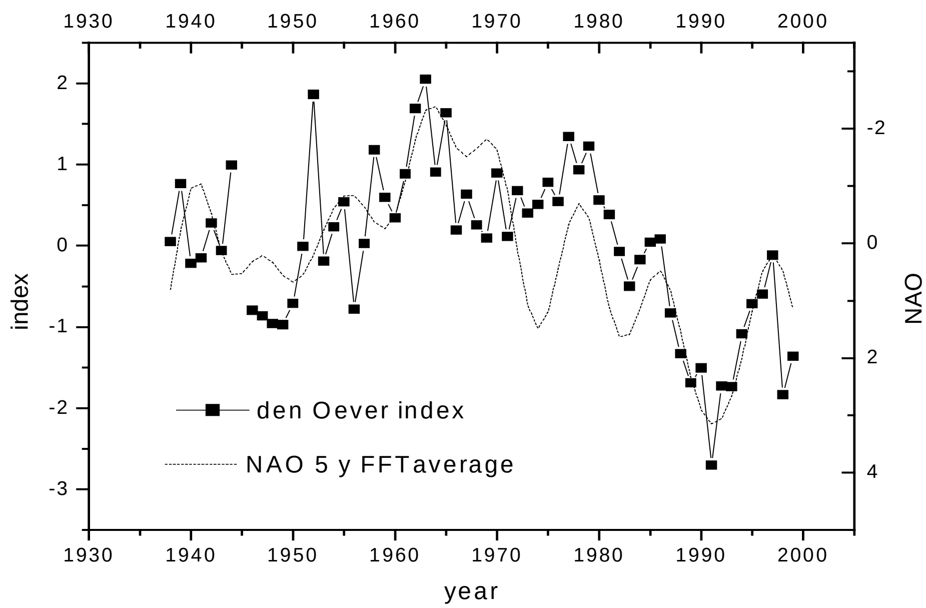


Figure 2.3.1.4. Recruitment index for glass eels at den Oever, Netherlands in Comparison with the smoothed average of the North Atlantic Oscillation Index, 1937-1998.

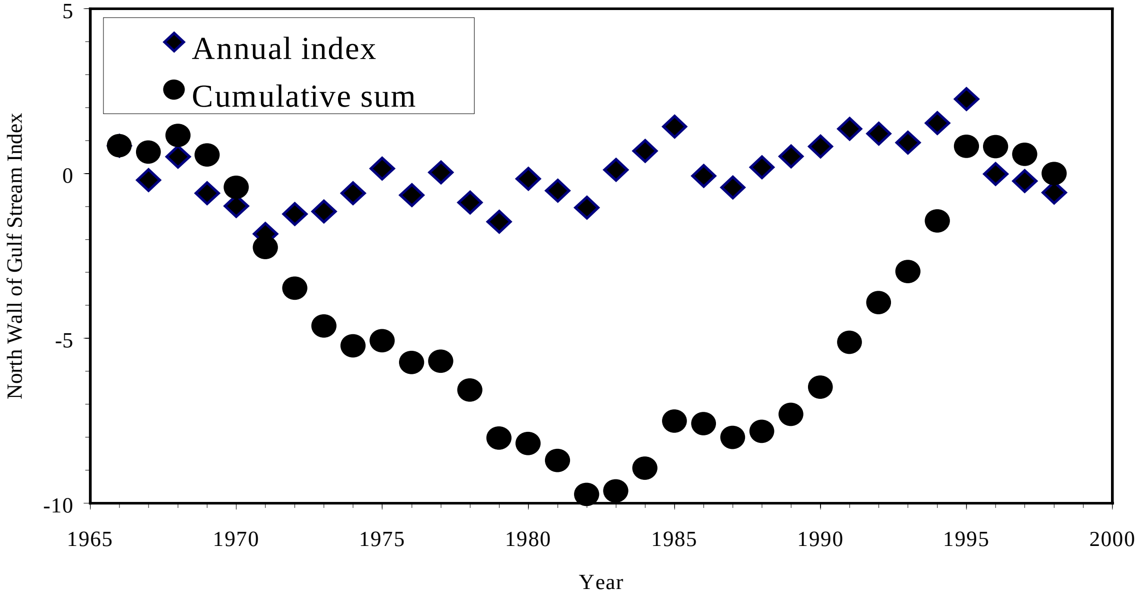


Figure 2.3.1.5. Annual index and cumulative sum of the index of position of the North Wall of the Gulf Stream in the western North Atlantic Ocean.

3 IMPACT OF FISHERIES IN SELECTED SYSTEMS ON EGG PRODUCTION

3.1 Impacts of Fisheries on Escapement

The American eel is subject to commercial fisheries at the glass eel, elver, yellow, and silver stages. This section presents the sparse information available on mortality from these fisheries, and its effects on subsequent egg production.

3.1.1 Elver fisheries

East River, Chester: The only estimates of exploitation rate of elver fisheries in North America were made in 1996, 1997 and 1998 at East River, Chester, Nova Scotia (watershed area 134 km^2). Commercial dipnetters caught 350,500 elvers in 1996 455,500 elvers in 1997 and 224,200 elvers in 1998 (Jessop in press). Research traps located at a barrier to elver passage, located approximately 100 m upstream from the commercial fishery, took 787,600 and 963,500 and 8,200 elvers, respectively, in the three years. Exploitation rates (commercial catch/(commercial + research catch) were 30.8% in 1996, 32.1% in 1997 and 5.8% in 1998. (Table 3.1.1.1).

If there is no density-dependent change in sex ratio, growth, survival, or emigration rate in subsequent stages, the reduction in egg production due to the elver fishery will be equivalent to the percent elver exploitation. However, such density-dependent effect are believed to occur.

3.1.2 Yellow/silver eel fisheries

Maryland: In Maryland waters of Chesapeake Bay, eels collected from the fishery during spring 1999 were subject to an overall disappearance rate of 0.5, based on a catch curve derived from an age-length key created from aged fish. Disappearance includes natural mortality, fishing mortality, and emigration. Natural mortality was estimated at 0.25, based on Anthony's (1982) method (3/maximum age in the sample). This means that the sum of fishing mortality and emigration was 0.25.

Prince Edward Island: Fishing mortalities in exploited waters of PEI were estimated through comparisons of length and age structure in fished and unfished areas. Eels of lengths 50-80 cm were strongly represented in samples from unfished freshwater ponds, and in samples collected in 2000 in the Pinette River estuary which is currently unfished (Figure 3.1.2.1). Lengths >50 cm were poorly represented in samples from exploited tidal waters, and from a sample collected in the Pinette estuary in 1973, at a time when the area was subject to commercial fishing. These size ranges are presumed to be females only, based on sex ratios of eels of this size measured elsewhere in eastern Canada.

For each of these sites, lengths were converted to age using a von Bertalanffy equation derived from otolith aging of 83 eels on the Boughton River, PEI. Disappearance was calculated by simulating a population equivalent to the number appearing in the modal age (Figure 3.1.2.2). An instantaneous annual disappearance rate was then applied to this population, leading to a simulated series of numbers at age. Differences between this series and the actual age distribution were squared and summed. The annual disappearance rate for the simulated series was then adjusted, and the value that gave the lowest sum of squared differences was taken as the best estimate of disappearance rate.

Mean disappearance rates of exploited and unexploited sites were 0.76 and 0.26, respectively. Fishing mortality was estimated as the difference between disappearance rates in exploited and unexploited areas. Three comparisons were made: tidal exploited vs ponds, Pinette 1973 vs. Pinette 2000, and tidal exploited vs. Pinette 2000. Estimated fishing mortalities were 0.54, 0.45, and 0.51, respectively (Table 3.1.2.1). The mean was 0.50. The mean disappearance rate for unexploited sites was 0.26. This is equivalent to the sum of natural mortality and emigration.

The effect of the PEI eel fishery on spawning escapement was estimated through a life table model which tracks mortality, numbers, harvest, and emigration during each year of continental life, and calculates egg production from escaped females which reach the Sargasso Sea. Major assumptions and inputs given in Table 3.1.2.2.

Under these assumptions, exploitation reduced female escapement by 89.9%, and egg production by 91.9%. The greater percentage reduction in egg production was due to the cumulative effects of fishing mortality, which reduce large females (which lay more eggs) proportionately more than smaller females.

The estimated reductions in female escapement and egg production for PEI as a whole would be less than these values, because there is no eel fishery in non-tidal waters, and there is minimal fishing effort in the central and western portions of the Northumberland Strait, which amount to about one third of PEI's coastline.

The analysis presented above is subject to several sources of uncertainty. A major point of uncertainty stems from the calculation of age distribution from lengths, via the von Bertalanffy curve. There are three main problems.

1) Eel growth is highly variable, so individuals may deviate widely from the expected growth trajectory.
2) Eels available for aging are those that have not been fished and have not emigrated. Fishing mortality and emigration rate are both size-related, so there is a truncation of larger individuals. This means that age-length curves are largely based on an unrepresentative sample of slow-growing animals.
3) Eel growth shows high spatial variability. Hence the age-length relation used in this analysis, derived from a single system, may not be representative of other areas of PEI.

A second source of uncertainty is the assumption, implicit in the calculation of disappearance rate, that recruitment was uniform during the years that fish present in the samples arrived in the system. In fact, recruitment is unlikely to be uniform in any fish stock. This uncertainty may be reduced to some degree in comparisons of samples taken in the same years.

A third source of uncertainty is the assumption that growth, mortality, and emigration schedules are similar between the compared sites. This assumption is questionable for habitats which differ (i.e., tidal estuaries vs. freshwater ponds). It is more tenable for similar habitats (Pinette estuary vs. other bays and estuaries).

In addition, natural mortality and emigration rates are poorly known, and their uncertainties will decrease the reliability of estimated fishing mortality and loss of egg production.

Given the above uncertainties, fishing mortality and reduction in egg production as estimated for PEI eel fisheries must be considered as crude and preliminary. Nevertheless, the similarity of fishing mortality estimates from the various comparisons (range 0.45 - 0.54) supports the belief that fishing mortality in exploited PEI waters is substantial, and, due to the cumulative effects of multi-year exposure to fishing, leads to a major reduction in egg production.

3.1.3 Silver eels

St. Lawrence Estuary: The estuary of the St. Lawrence River, site of a major silver eel fishery, is the only location in North America where fishing mortality of migrating silver eels has been measured.

In 1996 and 1997, 1,047 and 1,433 silver eels were captured and marked while migrating from the freshwater St. Lawrence watershed. Downriver, 28,714 and 51,558 eels were examined for marks in each of the respective years. Analysis conducted with pooled data (Petersen estimate) and with stratified data (Schaefer and Darrock-Plante estimates) indicated migrating populations of 470,000 silver eels in 1996 and 380,000 in 1997.

Based on landings of 119.5 t in 1996 and 111.8 t in 1997, exploitation rates in this fishery were 25% (18-33%) in 1996 and 20% (14-28%) in 1997 (confidence ranges are $\alpha = 0.05$). Escapement in the fishery was greater in 1996 (about 378,000) than in 1997 (about 288,000).

Because migrating silver eels are unlikely to face density-dependent effects in the ocean, it is probable that the 20-25% exploitation rates measured in this study produced similar decreases in egg production at the spawning grounds. It must be noted that exploitation at the migrating silver stage is only part of the anthropogenic constraints to which eels in the St. Lawrence system are subject. Prior to the estuarine fishery, these eels also face substantial mortality and habitat limitations due to upstream fisheries, dams, and pollution.

3.1.4 Natural mortality

Natural mortality estimates are required to evaluate the effects of fisheries on egg production because natural mortality rates influence life expectancy, and therefore the expectancy of spawning. Natural mortality has been estimated for elvers at one site, and for yellow/silver eels at two sites in North America.

East River, Chester: Jessop (2000) used trap counts and mark-recapture techniques to estimate that 99.45-99.68% of juvenile eels died between their arrival in May as elvers in the East River, Chester, Nova Scotia, and the subsequent October. This corresponds to instantaneous daily mortalities of 0.0612 and 0.0675. However, Jessop (2000) considered these mortalities to be abnormally high because of low pH in the river and heavy intra-specific predation.

Prince Edward Island: The analysis of length-frequency data for unexploited PEI waters gives estimates of 0.26 for natural mortality + emigration (Section 3.1.2 above), but this method does not separate the contributions of natural mortality and emigration.

Petite Trinité: Estimates of juvenile recruitment to and silver eel emigration from the Petite rivière de la Trinité, Québec, offer the opportunity to estimate cumulative natural mortality of the freshwater stage of the American eel. This river drains a watershed of 250 km^2 into the northwestern Gulf of St. Lawrence. No fishery is permitted on the river.

Dutil *et al*. (1989) provided an index of recruitment to the river, consisting of three counts of juvenile eels per night, every fourth night, made at a rocky ledge adjacent to a waterfall near the river mouth (Table 3.1.4.1). The eels were dominated by length classes under 110 mm, representing primarily age 1+ (arriving elvers are considered age 0+). This series was resumed with the same methodology in 1993-1996. In 1999, the method was repeated, and the total run was estimated by mark and recapture methods.

Total runs for 1982-1985 were estimated by applying the ratio of the night counts in these years to the night counts in 1999, to the 1999 run estimate. This was done in two ways: by using the total of counts conducted every four days, and the mean of the highest 10 counts for the season. Total runs for 1982-1985 ranged from 14,014 to 61,308 (total count method) and 15,382 to 67,294 (best 10 method) (Table 3.1.4.1). Mean estimated runs were 37,272 and 40,912 eels by the total and highest 10 methods, respectively.

The number of silver eels exiting the river in 1999 was estimated at 800, based on the number caught when the river was partially blocked. These eels ranged from age 15 to 24 years; hence the silver eels emigrating in 1999 entered the river between 1976 and 1985.

If we assume that the estimates of river recruitment for 1982-1985 are also valid for the 1976-1985 recruitment years, and that the estimates of silver eel emigration for 1999 are also valid for other years in which the 1976-1985 recruits emigrated, we can calculate the mean in-river survival rate of these animals as 800/37,272 (2.0%, total method) and 800/40,912 (2.1%, best 10 method).

Natural mortality in fishes tends to decrease with body weight. Natural mortality as estimated by Lorenzen's (1996) general equation for fish produced very low cumulative survivorships (under 0.002%) for the period between age 1 and age 5. For all practical purposes, cohorts were extinct by age 10. To derive a weight-based function that was consistent with a cumulative 2% survival between age 1 and age 20, as estimated for Petite Trinité, the Lorenzen mortality was multiplied by an adjustment factor. The 2% cumulative survivorship was achieved when the adjustment factor was set at 0.164. Under this scenario, instantaneous natural mortality at age 10 was 0.13, which is far lower than the M of 0.79 for age 10 eels using the unadjusted Lorenzen function (Figure 3.1.4.1).

Chesapeake Bay: Natural mortality of Chesapeake Bay American eels during spring 1999 as estimated by Anthony's (1982) method (3/maximum age in the sample) was 0.25.

Comments: The natural mortality + emigration estimate for PEI (0.26) and the natural mortality estimate for Petite Trinité (0.13 at age 10) suggest weight-specific natural mortalities that are substantially lower than those of most fish species. The case for low natural mortalities may be strongest in eastern Québec rivers and some Atlantic Canada rivers such as the Lattave River (Jessop 1987) and upper Saint John River where eels may be 30-40 years old before migration. In which there is a long residency period for yellow eels, such as Petite Trinité.

The Petite Trinité natural mortality derived from the Anthony (1982) method was 0.125, which is similar to the value based on estimates of incoming and exiting eels (0.13 for age 10). The Anthony (1982) and Lorenzen (1996) methods are based on relations that apply to general fish populations, while the PEI and Petite Trinité estimates are based on specific eel data. This could account for the difference in estimates, as could differences between Canadian and Mid-Atlantic environments. If yellow eels have low natural mortality, management regimes that tie maximum permissible fishing mortality to natural mortality may be constrained to low exploitation rates.

3.2 Fish Passage

3.2.1 Potential effects of dams on migration

In order to complete their life cycle, eels require access to and from the sea. Therefore, dams have the potential to seriously affect eel populations in upstream freshwater habitats. Greeley (1932) hypothesised that an increase in dam construction in New York state streams could reduce eel abundance. One of the clearest examples of dam effect on the

Atlantic coast is on the Richelieu River where recruitment has been seriously impeded since the reconstruction of two dams in the 1960s (R. Verdon, pers. comm.).

Based on their extensive review of the literature, Richkus and Whalen (1999) concluded that dams also have indirect effects including on habitat, population density, growth rate and sex ratio clearest. If upstream migration is impeded, eel density could be higher below dams than in other areas and is expected to lead to decreases in growth (R. Verdon, pers. comm.). Richkus and Whalen (1999) considered that lack of information made it difficult to quantify both the overall direct and indirect impact of dams.

Resource managers have rated the effect of dams as one of the most significant potential causes of the yellow eel population decline along the Atlantic coast. Where recruitment has been impeded by an unmitigated barrier, a marked ecline in the upstream eel population has occurred. In the St. Lawrence River system, for example, the impedance of upstream passage and turbine mortality of downstream migrant spawners is a possible cause of the decline in recruitment and abundance of eels in that system. Population modelling has revealed that the effects of dams on recruitment along the Atlantic Coast was one of the three most influential factors. Oceanic effects on glass eel production and cumulative effects of fishing were the most important.

3.2.2 Habitat change

Barriers can create reservoirs that are potentially valuable eel habitat. However, habitat benefits only accrue when upstream passage is provided through installation of passage structures or partially mitigated by stocking.

Eel sex may be associated with habitat type (Section 3.3.1). Therefore, hydropower impoundments could contribute more females than the river in a natural state, and losses through turbine mortality may be compensated by production in the reservoir. An example of this has been documented in the upper reaches of the Ernes Lake system in north-west Ireland, which are characterised by low density of fast growing females (M. Matthews, pers. comm.).

3.2.3 Upstream fish passage facilities

The effect of barriers on upstream passage depends on how easily the structure can be ascended by the size of immigrating eel present (EPRI 1999). Successful upstream passage may be more likely close to estuaries than farther upstream, because small eels are better able to ascend over obstructions. Although eel are generally considered good climbers, vertical falls, even those a few centimetres high, and moderate to high velocity currents can prevent upstream migration of yellow eels (Porcher 1992).

The height of the structure, presence of seepage flow and surface roughness, often factors related to the age of the structure, can alter the scalability of a dam. This was clearly shown on the Richelieu River where the rebuilding of two old cribwork dams in the 1960's led to a gradual decrease in silver eel landings since 1981. Monitoring of a pass on the upper dam suggested a blockage at the lower dam (R. Verdon, pers. comm.). Without knowledge of the type of structure present at each site, it is not possible to determine the total impact of installed dams.

Where barriers are impassable, ship locks can allow upstream passage. On the St. Lawrence River, the Beauharnois lock allows significant passage. A reduction in ship movement through the locks has been correlated with a decrease in upstream passage at the fish ladder at an upstream fish ladder (R. Verdon, pers. comm.).

Where upstream passage is a concern, cost effective facilities can be installed to mitigate the blockage. Traditional fishways designed for other species have not proven ineffective for eels (J. Therrien, pers. comm.), but cost-effective upstream passage facilities for upstream migrating eels have been installed in Europe and to some extent along the U.S. Atlantic Coast. A simple eel ladder with a 1.1m wide entrance on the Chambly Dam on the Richelieu River has allowed passage of 57% of the eels present at the dam face after one year of operation and close to 70% after two years (R. Verdon, pers. comm.).

3.2.4 Monitoring of juvenile recruitment

Counts of eels ascending the eel ladder on the Moses-Saunders Dam on the St. Lawrence River were carried out between 1974 and 1999. These data were used as a recruitment index of daily passage into Lake Ontario (Casselman *et al*. 1997). The peak recruitment occurred in 1982 (27.489 passed per day in the peak period) but was down to 27 eels in 1999, a drop of three orders of magnitude. This index is one of the primary lines of evidence for a recruitment decline at the extremity of the species range.

Barriers increase access to elvers for transfer and recruitment monitoring. The efficiency of the system installed and the monitoring methodology may change over time. Any changes to these aspects of operation must be carefully documented and the resultant bias must be quantified at the time of change.

3.2.5 Downstream passage

The passage of emigrating silver eels must be available so that reservoirs can contribute to spawning escapement. Where dams are associated with power generation, reported turbine induced mortalities have ranged from 6% to 37% (Richkus and Whalen 1999). Studies indicate that mortality increases with the size of eels and is highest for small turbines with high head (Monten 1985; Larinier and Dartiguelongue 1989).

Females silver eels are more vulnerable than the smaller males to turbine mortality during passage through power stations. Females are common inland and likely to encounter turbines upon spawning emigration. Hydro-power stations have the potential to have a greater impact on females, and effort should be concentrated on protecting these large eels.

Where multiple dams are present on a river system, turbine mortality is cumulative. A 26.5% mortality rate has been reported for the Moses-Saunders Dam on the outlet of Lake Ontario and another 18% on a second dam of the St. Lawrence. Together, these structures are responsible for three quarters of the total mortality (passage + harvest). Any modification that reduces turbine mortality (e.g., modification of turbines or a change in operating regime) would lead to an increase escapement for American eel from Lake Ontario.

The effectiveness of protective measures for downstream passage is poorly understood. Mitigation, such as spilling and shut down, is possible where runs of silver eel can be predicted and correlated, for example, with rainfall events or sudden drops in barometric pressure or temperature (Boubée *et al*. in press; A. Haro pers. comm.; C. Durif pers. comm.). Where downstream migration triggers are less well defined or unknown, other protective measures will be required. *The effectiveness of behavioural measures such as sound or light barriers are unclear, and further research is recommended to determine the feasibility of these approaches.*

Although ideally safe downstream passage of emigrant eel should be provided at large hydro dams, there is as yet no cost-effective means of protecting eels from entraining at large dams. In these cases compensation mechanisms such as protection of downstream habitat and transfer of juveniles to under-populated habitat with free downstream access could be considered.

Entrainment and turbine losses are not a problem at all dams. However, if free flow over the dam is not available during the downstream migration period, emigrants will be unable to progress downstream. In these situations, delay in downstream passage may lead to potential loss of migration synchronisation. Loss of condition as the result of the delay may compromise the ability of eels to reach spawning grounds and reproduce successfully.

3.2.6 Facilities and management action needed to ensure sustainable fisheries

Once a passage problem has been identified, a means of surmounting the barrier should be considered. Where the upstream habitat is suitable and downstream passage is not a major issue, an effective means of allowing the upstream passage for the size of eels that are blocked should be provided.

There is a need to document and describe cost-effective technology allowing upstream passage. European and New Zealand experience indicates that systems that include climbing media suitable for the range of eel sizes present can be effective for low head dams (less than 10 m). For higher dams, lift and trap and transport should be considered. Where multiple dams are present or where numbers of juvenile eels are simply not available (for example because of other effects downstream) mitigation in the form of trap and transfer may be considered. It is important to recognise however that the strong migration behaviour exhibited by juvenile eels may lead them to accumulate at the next upstream barrier.

3.3 Other Anthropogenic Effects

3.3.1 Physical habitat change

Human actions over the past 250 years have significantly reduced the amount of habitat available to eel. This loss of habitat would have significantly reduced the spawner biomass. Anthropogenic blockages (dams and weirs) have resulted in an overall 84% decrease in available habitat to American eel in the U.S. Atlantic states (Busch *et al*. 1998; Table 3.2.1.1). In the North Atlantic, the reduction in river length with free access has been reduced by 85%. For the Mid Atlantic area, the reduction is 88%, the South Atlantic 82%, and the Great lakes area 82%. The extent to which these blockages are a barrier to upstream migrating eels is unknown. Lost production due to blockages cannot be estimated because eel density in the areas surveyed is unknown.

The alteration of riverine habitat for power production, or the creation of lakes for human recreation or the enhancement of other fish species, may change the sex ratio of emigrating spawners. There is evidence that particular sexes are associated with different types of habitat in some systems. In some Maine systems, freshwater stream habitat is associated with escapement of male silver eels, while lakes produce almost exclusively female silver eels. Females and males may have different habitat requirements for optimal biomass, and the reduction of available habitat for one sex could reduce the amount of spawner biomass produced and change the sex ratio of emigrating adults.

3.3.2 Chemical habitat change

3.3.2.1 Contaminants

Due to their benthic habit, long life, and high fat content eels are particularly likely to accumulate contaminants (Couillard *et al*. 1997). However, the impact of contaminants on the survival and reproductive success of this species is poorly understood (Couillard *et al*. 1997; ASMFC 2000). Eels in the St. Lawrence River showed pathological liver lesions associated with contamination levels of organochlorine compounds, but ovarian development was not affected (Couillard *et al*. 1997). Eels are known to persist in areas with high pollution levels (e.g., Hudson River, St. Lawrence River) and are a potentially valuable sentinel species for pollution monitoring. However, pollutants have been shown to affect the survival, growth and reproductive success of other fishes. In addition, Anguillid species may not be as able to adapt to pollution as other species of fish, due to their panmictic reproduction which does not allow for selection of locally-adoptive pollutant-resistant genes.

3.3.2.2 Productivity

Change in productivity is often associated with change in growth, generation time and fecundity in fishes. In the Hudson River, for example, eels of the same size tended to be older in fresh compared to brackish environments. Changes in productivity in the Great Lakes could affect the Lake Ontario-St. Lawrence River eel stock. Female fecundity should be maximised with maximum size and is compromised when early maturation at a small size occurs. Females appear to prefer estuaries, lakes and large rivers that are productive. At least in small high gradient streams of lower productivity, males predominate. This pattern suggests that changes in productivity could influence sex distribution and sex ratio.

3.3.3 Biological habitat change

3.3.3.1 Introductions

Game fish: Stocking of game fish into areas where eels occur is common in many areas. Management sometimes favours the proliferation of other species in habitat where eels occur through stocking of game fishes. If such stocking results in competitive interactions for food and habitat, it could negatively impact eel growth. This could have implications for the size at spawning and the number of years needed to produce a spawner. Alternatively, direct predation by the introduced species on eel, especially on the young of year and juvenile stages, would reduce survival and thus the number of spawners emigrating years later.

Stock enhancement with young eels: There is no significant use of glass eel and elver stocking into North American systems as a means of enhancing natural populations. The apparent declines in escapement and recruitment discussed elsewhere in this paper have only recently come to the attention of Canadian and the American fisheries managers, and stocking could be considered as a viable solution to stock decline in the future. Stocking should always be governed by the principles of adaptive management and accompanied by an evaluation program, so that effects can be measured and practices changed as necessary. In considering stocking as a management option, various issues must be considered as follows:

- Stock transfers can result in the spread of parasites, diseases and non-native organisms which could negatively impact eels or other species in the recipient water body.
- Consideration should be given to the possibility that stocking might mask declines in “wild” recruitment, leading to potential complacency over the true status of a wild stocks. Regular assessment of mixed stocks and wild fisheries, in conjunction with documented stocking levels, might enable tracking of stocked cohorts within a system.

- The existing biodiversity of systems should not be compromised by inappropriate introductions of American eels. It should not be assumed that eels should be abundant in all waters, any more than any other species. There may be cases where other species take preference, or where eels would be an unwanted predator.
- When population density is high, eels may tend to become male. High densities of juveniles have been associated with more males in European eel (Helfman *et al*. 1987), but the limited examination of this issue in *Anguilla rostrata* has not produced a firm prediction of sex determination with density (Helfman *et al*. 1987). Krueger and Oliviera (1999) reported evidence that high density favours production of males. However, there was an inverse relationship between male abundance and density across broad regions of the United States Atlantic coastal states (Kleckner and McCleave 1985). If there is an effect of density on sex determination, then stocking of young of year eels could impact the sex ratio and resultant spawner biomass. Increased intraspecific competition may be expected to reduce the growth of resident eels.

Swim bladder parasite: *Anguillicola crassus* is a nematode parasite of Anguillid eels. It originated in the Japanese eel (*Anguilla japonica*) and has been documented in the European eel (*A. anguilla*) and recently in American eel (*A. rostrata)*(Barse and Secor 1999). *A. crassus* has been implicated in acute mortality as well as internal injury and growth impairment. Part of its life cycle occurs in the eel swim bladder, and its departure through the swim bladder wall can cause injury and scarring. These effects on the swim bladder could impact a silver eel's ability to travel to the Sargasso Sea spawning grounds and thus its reproductive success. The long-term impacts of *A. crassus* on Anguillid species are unknown.

Zebra mussel: The invasion of the Great Lakes region by zebra mussel has resulted in greatly increased water clarity. This transparency could impact the available habitat, eel behaviour and consequent growth.

3.3.3.2 Changes to spawning habitat

Sargassum is a large macroalgae which floats in large masses in the Sargasso Sea where eels spawn. It provides habitat to many fish, birds, and reptiles and is a major source of energy in this vast area. This plant is harvested for fertiliser and animal feed and its exploitation is unregulated. Harvest of Sargassum weed in the Sargasso sea has potential to degrade the amount and quality of spawning habitat and impact *A. rostrata* early life history (ASMFC 2000). The harvest of Sargassum in U.S. Economic Zone is to be phased out upon direction of the South Atlantic Marine Fisheries Council.

Table 3.1.1.1
Estimates of natural and fishing mortality in American eels. Mortalities giving rate per unit time are instantaneous. Mortalities given as percentages are finite (equivalent to exploitation rate).

Site	Stage	Natural mortality	Fishing mortality	Natural mortality + emigration rate	Fishing mortality + emigration rate
East River, Chester, Nova Scotia	Elver	0.0612-0.0675 day^{-1}	30.8-32.1%		
Petite Trinité	Yellow	0.09 - 0.73 yr^{-1}	0		
St. Lawrence estuary	Silver		20-25%		
Prince Edward Island	Yellow/silver		0.5 yr^{-1}	0.26 yr^{-1}	
Chesapeake Bay, Maryland	Yellow	0.25 yr^{-1}			0.25 yr^{-1}

Table 3.1.2.1
Comparison of instantaneous disappearance rates of eels in exploited and unexploited waters of Prince Edward Island, and calculation of fishing mortality.

Exploited sites		Unexploited sites		Fishing mortality
Location	Disappearance rate	Location	Disappearance rate*	
Tidal waters	0.78	Freshwater ponds	0.25	0.54
Pinette estuary, 1973	0.73	Pinette estuary, 2000	0.28	0.45
Tidal waters	0.78	Pinette estuary, 2000	0.28	0.51
Mean	0.76		0.26	0.50

*Equivalent to natural mortality + emigration rate

Table 3.1.2.2.
Assumptions of the life table model used to estimate effects of fishing mortality on egg production.

Natural mortality and emigration rate	Natural mortality + emigration = 0.26, which is the mean disappearance rate calculated for unexploited PEI sites. It was assumed that emigration begins at age 8, and that natural mortality and emigration contribute equally to disappearance. Lorenzen's (1996) general mortality function was applied to weights-at-age derived from an age-weight von Bertalanffy curve for the Boughton River system. This gave mortalities of 0.52 to 0.43 for ages 6 to 16. The mortality from the Lorenzen function was multiplied by an adjustment factor, which was varied until the mean natural mortality for ages 8-16 was 0.5 x 0.26. The adjustment factor required to do this was 0.27.
Elver fishery	None
Directed fishery for silver eels	None
Mortality between emigration and the spawning ground	From Lorenzen's (1996) general weight function (unadjusted)
Fecundity	Barbin and McCleave's (1997) weight-based fecundity formula (based on data collected in Maine).
Yellow/silver eel fishing mortality	0 in unexploited trial, 0.50 in exploited trial.
Recruitment to the fishery	50.8 cm, or age 6+

Table 3.1.4.1

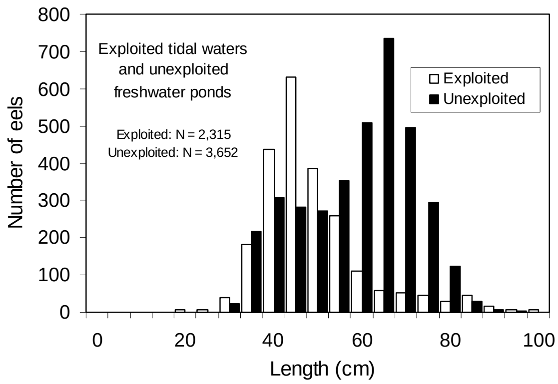
Counts and estimated recruitment of juvenile eels to the Petite rivière de la Trinité.

Date	Total of nightly counts								
	1982	1983	1984	1985	1993	1994	1995	1996	1999
16 Jun									12
20 Jun									87
24 Jun									164
28 Jun								595	57
2 Jul							138	1,402	110
6 Jul						32	1,135	104	48
10 Jul					1,203	49	682	41	27
14 Jul					575	48	602	1,072	208
18 Jul					358	185	181	163	84
22 Jul					163	116	263		47
26 Jul					475	154	257		22
30 Jul					335	97	334	389	19
3 Aug					328	35	234	820	10
7 Aug					160	20	84	618	10
11 Aug					9	9	137	217	6
15 Aug					75	18		126	8
19 Aug								111	14
Seasonal total	4,576	4,389	1,046	1,117	3,681	763	4,047	5,547	933
Ratio count total:1999 count total	4.9	4.7	1.1	1.2					
Estimated run	61,308	58,802	14,014	14,965					
Mean of the best 10 counts	458	439	105	112					85
Ratio mean of the best 10:mean of the best 10 counts in 1999	5.4	5.1	1.2	1.3					
Estimated run	66,979	64,242	15,310	16,350					

Notes:
From 1982 to 1996, three counts per night were made at 21:00h, 22:00h and 23:00h every 4 nights.
Individual counts for 1982 to 1985 are not avalaible.
In 1999, entries are the total of the catch + observed eels on the same rock at the same hours.
The estimate of eels recruiting in 1999 (mostly <110 mm, 1+) was 12,500.

Table 3.2.1.1. Historic and current potential eel habitat in the Eastern United States (Busch *et al*. 1998).

Region	Watershed Name	Historical length (km)	Current length (km)	Lost length (km)	Number of dams
North Atlantic	St. John River Basin	11335	148	11187	37
	Penobscot River Basin	15245	207	15038	75
Maine to	Kennebec River Basin	9186	208	8978	97
Connecticut	Androscoggin River Basin	4467	195	4272	95
	Maine Coastal - St. Croix	10884	5166	5718	98
	Saco, ME, NH, MA	9414	1685	7729	212
	Merrimack River Basin	11006	10	10996	533
	Connecticut River Basin	20874	99	20775	941
	MA - RI Coastal Area	7886	1589	6297	708
	Connecticut Coastal	10335	1188	9147	713
	St. Francois River Basin	850	1	849	13
	Total	111482	10496	100986	3522
Mid Atlantic	Richelieu Basin including Lake Champlain drainage	9126	1	9125	235
New York	Upper Hudson	22389	1	22388	660
through Virginia	Lower Hudson - Long Island	7781	1431	6350	519
	Delaware Coastal Area	26934	5148	21786	1068
	Susquehanna River Basin	52331	251	52080	684
	Upper Chesapeake	14884	8862	6022	157
	Potomac River Basin	28140	3281	24859	443
	Lower Chesapeake	37727	5559	32168	884
	Total	199312	24534	174778	4650
South Atlantic	Chowan-Roanoke Coastal	36775	3632	33143	371
	Neuse-Pamlico Coastal	23324	12452	10872	445
North	Cape Fear Coastal	20471	5990	14481	626
Carolina	Pee Dee Coastal	35880	6139	29741	1034
to Florida	Edisto-Santee Coastal	41504	7003	34501	1942
	Ogeechee-Savannah Coastal	34604	4508	30096	1028
	Altamaha-St. Marys Coastal	37172	4673	32499	1353
	St. Johns Coastal	82334	6582	75752	40
	Southern Florida Coastal	8044	4893	3151	105
	Total	320108	55872	264236	6944
Great	Eastern Lake Erie	113	66	47	4
Lakes	Southwestern Lake Ontario	8076	1827	6249	67
New York and Ontario to Québec	Southeastern Lake Ontario	16156	2877	13279	159
	Lake Ontario-St. Lawrence	5740	622	5118	225
	Total	30085	5392	24693	455
	Grand Total	660987	96294	564693	15571



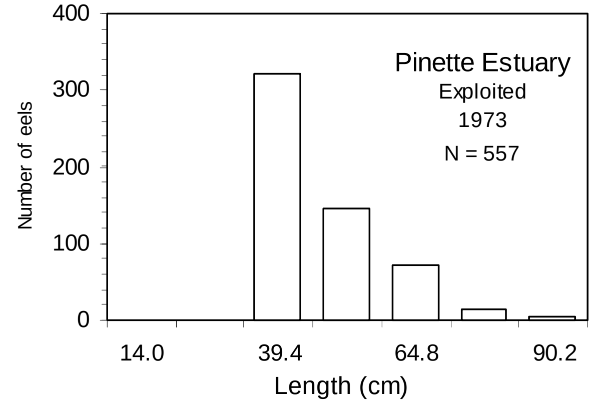
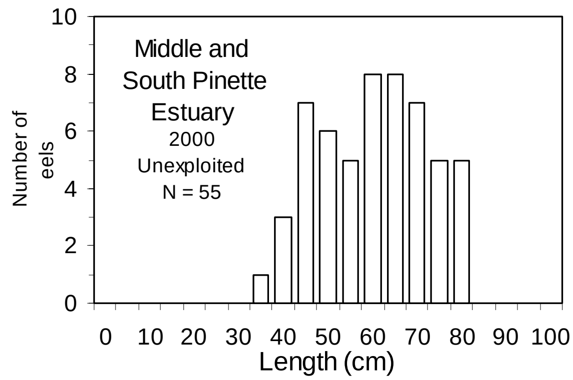
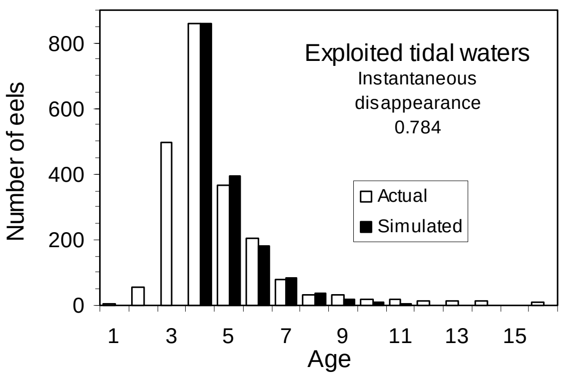
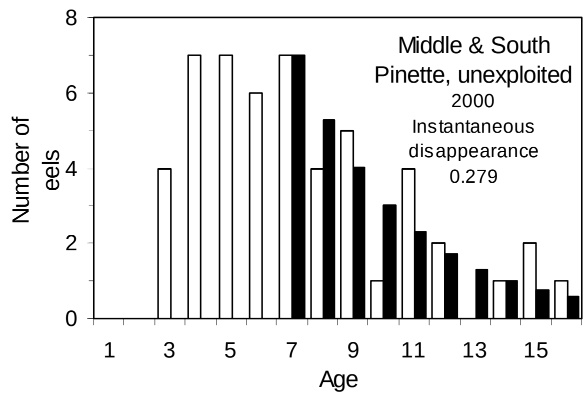
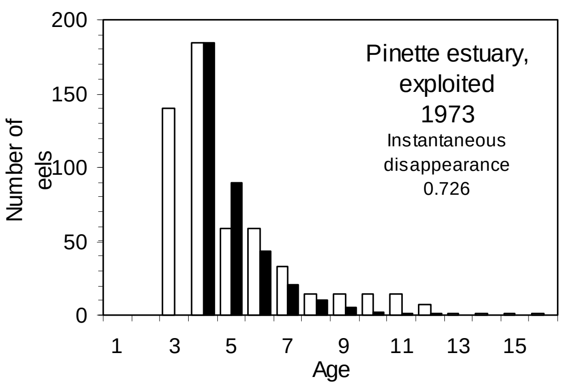


Figure 3.1.2.1. Length frequencies of eels in exploited and unexploited waters of Prince Edward Island, Canada.









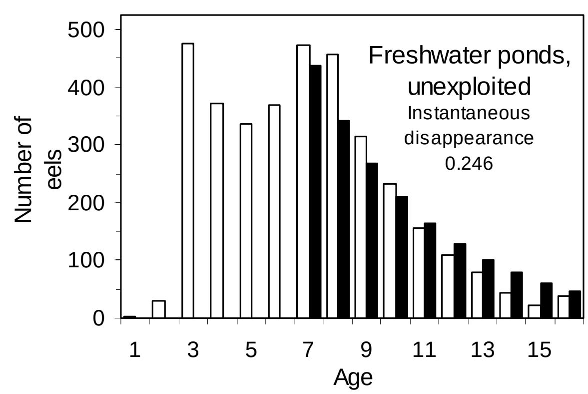


Figure 3.1.2.2. Actual and simulated age frequencies of eels in exploited and unexploited waters of Prince Edward Island. Actual age frequencies are derived from length frequencies, using a von Bertalanffy age-length function.

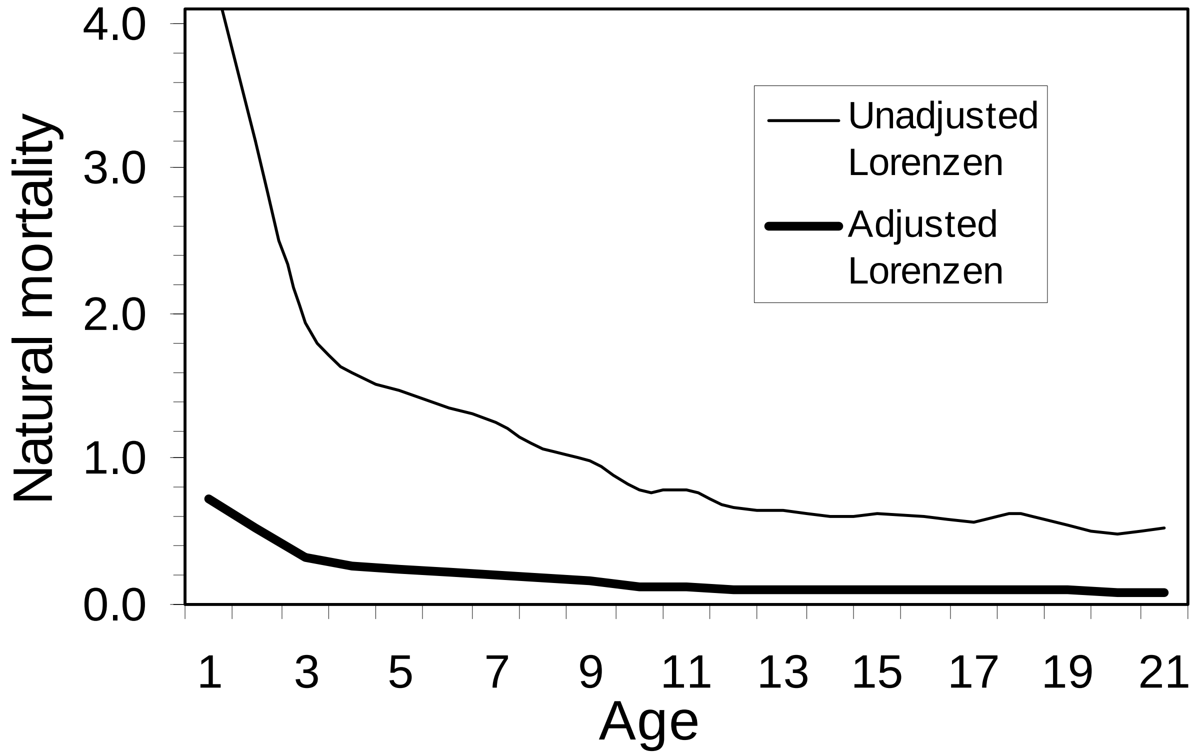


Figure 3.1.4.1 Instantaneous natural mortalities of eels on the Petite rivière de la Trinité, according to the unadjusted general fish equation of Lorenzen (1996), and the Lorenzen equation adjusted to make survival from age 1 to age 20 equal to 2%.

4 OPTIONS FOR DEVELOPING ESCAPEMENT TARGETS FOR SELECTED SYSTEMS

4.1 Evaluation of Human and Natural Impacts on American Eel Recruitment

In coastal fisheries uncertainty in the outcome of management is often the result of incomplete knowledge on life cycles and key demographic parameters. Resource management of American eel epitomises this dilemma: because spawning eels have not been sampled, there is no direct means to relate spawning stock to recruitment in a conventional manner (e.g., Beverton and Holt 1957), nor are there strong theoretical grounds to relate spawning stock to recruitment. Nevertheless, in the face of this uncertainty, the *Precautionary Approach* directs managers to take action to insure against future harm to the resource, making use of the best available understanding of life history attributes and vital rates.

In this section, the use of a Paulik diagram (Paulik 1973) serves to summarise key elements of the life cycle of eels and classify possible population-level consequences of natural and anthropogenic impacts. The Paulik diagram, originally developed for Pacific salmon, depicts a series of transition functions among critical life stages and provides a framework to evaluate population responses to single or multiple impacts. The Paulik diagram may be particularly useful for life cycles where key stages are thought to be regulated by density dependent processes (Nash *et al*. 1996).

The American eel life cycle can be separated into two broad phases:

a) An oceanic phase in which silver eels migrate to the Sargasso Sea, spawn, and die; eggs and leptocephali drift; and glass eels disperse into near-shore habitats of North America. Very little is known about this phase, and what is known is largely outside of the influence of management.

b) An estuarine/freshwater phase in which glass eels and elvers disperse throughout watersheds, and grow into a sedentary yellow eel stage. For this phase there is probably sufficient attainable knowledge to recommend action to maintain populations within limits imposed by recruitment and local productivity.

It is reasonable to suppose that the oceanic phase is driven principally by density independent controls whereas in the estuarine/freshwater phases, density-dependent processes can predominate, with production limited by availability of suitable habitat or food. These two phases are further subdivided into four key life cycle transitions:

1. silver eel production → egg production.

2. egg production → glass eel/elver (“pre-settlement”) production.

3. elver production → yellow eel production.

4. yellow eel production →silver eel production.

The first two transitions occur principally in the ocean, the latter two correspond to estuarine/freshwater phases. In a counter-clockwise rotation, four plots are combined leading from and returning to silver eel production (Figure 4.1.1, see legend for additional information on interpreting diagram). A summary of possible impacts for each transition is presented in Table 4.1.1.

4.1.1 The Paulik diagram

Silver eel → Egg transition: American eel life history differs substantially across latitude, habitat, and gender leading to widely differing maturation schedules. Following metamorphosis, all silver eels leave freshwater and estuarine habitats, initiating long-distance oceanic migrations (> 1000 km) to the Sargasso Sea where spawning occurs from February to April (Schmidt 1922; McCleave *et al*. 1987). Spawning has never been directly observed. American eels spawn small eggs (c. 1 mm diameter) and fecundity increases exponentially with length: 40 cm and 80 cm long silver eels yield 1×10^6 and 8×10^6 eggs, respectively (Wenner and Musick 1974; Barbin and McCleave 1997).

Overall, egg production should increase as a linear function of silver eel production. Because the Sargasso Sea is vast, no regulating mechanism seems likely.

Depensatory effects of low silver eel production on egg production (shown by dotted line in Figure 4.1.1) can be envisioned for scenarios leading to poor mating success. If for instance, the sex ratio becomes skewed towards females at low densities of estuarine/freshwater stages (Kreuger and Oliveira 1999; Oliveira 1999), then insufficient males may be present to ensure fertilisation. Alternatively, if spawning aggregations are disrupted at very low spawner densities, then the probability of mating and fertilisation in the Sargasso Sea, an enormous spawning habitat, could be impaired.

Egg glass eel/elver transition: Larvae (leptocephali) of the American eel are transported passively by oceanic currents, particularly the Gulf Stream, adjacent to the North American continental shelf. Larvae metamorphose into unpigmented juveniles (glass eels) and glass eels transit across the continental shelf. Dispersal from the Sargasso Sea to nearshore environments requires 6-16 months. Glass eel enter nearshore coastal habitats, estuaries, and usually migrate into non-tidal fluvial habitats. Dispersal into upper reaches of watersheds may continue after the glass eel has become a pigmented juvenile (elver). At some point however, the elver settles into the benthos and adopts a more sedentary life style. For convenience, the transition between egg and elver production only includes the pre-settlement dispersal period.

The transition between egg and elver stages is primarily influenced at both oceanic/decadal and continental shelf/seasonal scales that affect larval dispersal and juvenile ingress into estuaries. Effects are stochastic and because these operate in open systems, the conversion of eggs to elvers is modelled according to linear function with wide confidence intervals. As glass eels move into shallow coastal and estuarine habitats, it is possible that piscine and avian predation control regional elver abundance, perhaps in a density dependent manner. Still, abiotic controlling processes are expected to exert dominant control on this transition.

Depensatory effects of low egg production on elver production (shown by dotted line in Figure 4.1.1) might occur if successful dispersal of larvae is dependent upon their distribution or concentration. At low spawner densities, resulting larvae distributed in relatively few patches might not successively be entrained into oceanic/tidal currents that are likely to bring them to continental shelf/nearshore waters. If dispersal of larvae to continental shelf areas is concentration dependent (i.e., ideal free distribution as proposed by Smogor *et al*. 1995), ingress would be impaired.

Elver Yellow eel transition: The distinction between elvers and yellow eels is rather arbitrary, as there is no clear morphological or physiological difference between the stages. Here we designate elvers as pigmented juveniles <10 cm. Elvers and yellow eels are sedentary, showing strong affinity to local regions (100 – 10,000 m) in nearshore coastal environments, estuaries, and non-tidal fluvial and lacustrine habitats. Precise site affinity ("homing") within these stages has been demonstrated through telemetry, tagging, and mechanistic studies. These stages show high rates of phenotypic plasticity in growth, sex differentiation, maturation size and age, diet, morphology, and habitat shifts. Many of these life history attributes are associated with habitats that are colonised by elvers/yellow eels. For yellow eels captured from major estuarine systems, Helfman *et al*. (1987) showed an inverse latitudinal trend in growth rate and a positive latitudinal trend in size and age at maturation. While Helfman's (1987) proposed sex ratios also showed a latitudinal trend–increasing females with increasing latitude – more recent data (Krueger and Oliveira 1999) indicates that many males are produced at the northern part of the species range. Recently, Oliveira (1999) has provided additional evidence for Tesch's original proposal (Tesch 1977) that sex ratio is most likely determined by density during the elver or early yellow eel stage. Recent analyses of otolith microchemistry indicate that yellow eels show different modes of habitat use – stage-long residency in freshwater, estuarine or coastal waters, and habitat shifts from freshwater to brackish water. These modes of habitat use have consequences to growth and maturation rates. Otolith microchemical analysis should allow habitat use during the yellow eel phase to be hind-cast from silver eels and thereby allow silver eel production to be related to broad categories of freshwater, estuarine, and coastal habitats (Secor and Rooker 2000).

Because site-affinity and density dependent processes are well documented for elver/yellow eel stages, compensatory functions were chosen to represent the transition between elvers and yellow eels. Territoriality, space and forage limitation, predation, and cannibalism are conceived as possible mechanisms leading to either a saturating or an over-compensating function. Either of these forms results in high degrees of regulation linked to habitat.

Yellow eel silver eel transition: Yellow eels undergo fundamental physiological and morphological changes during their metamorphosis to silver eels. Pigment and swim bladder morphology change, eye diameter increases, and the digestive system degenerates. Associated with these trends is recruitment of lipid and proteins to gonads. Male silver eel metamorphosis occurs at significantly smaller sizes (<40 cm) and younger ages than for females (>50 cm). Female silver eels are substantially larger and older in the northern part of the species range than in the southern part. During and after metamorphosis, silver eels initiate migrations out of watersheds and into coastal environments.

The transition to silver eels from yellow eels must be energetically costly. Additional energy reserves must be sequestered to undertake long distance ocean migrations and fully ripen eggs prior to spawning. Growth during the years leading up to metamorphosis must therefore control the transition. Because growth is likely regulated by density during the yellow eel stage, the functional transition is again modelled as either a saturating or an over-compensating function.

4.1.2 Evaluation of impacts

Functional relationships proposed for major life history transitions are speculative but permit likely consequences of single or multiple impacts to be tracked through the entire life cycle. Initially, it's useful to consider an unimpacted population (Figure 4.1.2.1). A given level of silver egg production can be converted to egg production, elver production, etc. When the Beverton-Holt model of compensation is input during elver→silver eel transitions, then the deterministic functions alone would lead to a stable production of recruits. Alternatively, over-compensation transitions during the estuarine/freshwater phases should lead to an oscillating abundance level, symmetrical about some carrying capacity for these environments (Figure 4.1.2.1).

Next consider the loss of spawners to a low level, under a system of depensation at either the silver eel→egg transition or the egg glass eel/elver transition. Tracking the consequences of these functions through the life cycle shows a downward spiral that would lead to extinction (Figure 4.1.2.2). Impacts that could lead to reductions in silver eel production include exploitation and dam passage (see Section 3). Impacts that could reduce egg production include *Anguillicola crassus* parasitism, pollution, and altered sex ratios. The effects of reduced egg production can be exacerbated by oceanographic conditions unfavourable for larval survival and dispersal to continental shelf waters (Figure 4.1.2.2).

The effect of increased silver eel escapement on recruitment of elvers and yellow eels will be heavily conditioned by the expected compensatory functions. Thus proportional improvements of recruitment from increased spawner escapement should not be expected. Still, an effect of increased freshwater/estuarine habitat (increased passage, improved habitat, stocking into unoccupied habitats) can result in improvements to production of subsequent generations recruitment of elvers and yellow eels (Figure 4.1.2.3).

4.1.3 Spawning escapement and the *Precautionary Approach* – life history insights

There are important caveats to the presented Paulik framework related to complexity in age structure (overlapping generations), phenotypic plasticity, environmental sex determination, and high spatial heterogeneity in elver/yellow eel production. Given these limitations, the evaluation of impacts supports two findings:

1) The possibility of depensation at low spawning stock (Liermann and Hilborn 1997; Ludwig 1998) supports management for some minimum level of spawning stock escapement. While it seems unlikely that recent American eel spawning escapement has approached this level, within ICES there is concern that the more highly exploited European eel may be showing signs of a downward spiral in elver recruitment, perhaps due to the combined effects of low escapement and poor oceanographic conditions (ICES 1998). An analytical approach for determining escapement targets is presented in the next section.
2) Strong regulation during the estuarine/freshwater stages indicates that increases in spawning escapement may result in increased F_1 elver recruitment, however this increase is unlikely to result in proportional changes in recruitment in subsequent generations. Habitat increase in estuaries and freshwater environments (e.g., increased passage) is viewed as a principal means to improve recruitment of elvers and yellow eels in current and future generations.

4.2 Biological Reference Points and the *Precautionary Approach*

ICES has recognised that a precautionary approach should be applied to fishery management and that reference points are key concepts in its implementation (ICES 2000). These reference points could be stated in terms of fishing mortality rates or biomass with the intention of ensuring that the stocks and their exploitation remain within safe biological limits. Implicit in the development of reference points is the assumption that there is a relationship between spawning stock and recruitment. The precautionary approach, dictates that unless it can be scientifically demonstrated otherwise, such a relationship between stock and recruitment should be assumed to exist (ICES 1997/Assess:7).

4.2.1 Reference points

The value of establishing reference points depends upon the consequences to the resource of variations in spawning stock abundance. There are two hypotheses to consider in deciding whether spawning stock reference points are appropriate for the American eel; recruitment dependent on spawning stock size versus recruitment dependent upon environmental conditions.

Consequences of managing for spawning stock size to future recruitment dependent upon the factor regulating recruitment

	Factor regulating recruitment	
Management approach	Spawning stock	Environment
Ignore spawning stock size	Risk of crashing the stock	Variable and unknown rate of recruitment
Manage for spawning stock size	Reduced risk of crashing the stock	Variable and unknown rate of recruitment

The prudent action under the conflicting hypotheses is to minimise the risk of crashing the stock. This would be achieved by assuming dependence of recruitment on spawning stock size, consistent with a *Precautionary Approach.*

There are two general classes of reference points:

1) Limits: set boundaries which define safe biological levels. Limits are often referred to as thresholds and are intended to minimise the risk of the stock falling below a minimum size (Mace 1994; ICES 1997/Assess:7).
2) Targets: are reference levels to aim for and are intended to meet management objectives such as achieving yields close to the maximum attainable level (Mace 1994).

Target reference points would be more conservative than limit points. Target mortality rates would be lower than the limit mortality rates whereas target spawner biomass reference points would be higher than limit spawner biomass levels (Figure 4.2.1.1). The management strategy would be designed to avoid exceeding the threshold and if the threshold is exceeded, then substantial reductions in mortality, including restrictions or prevention of the activity causing the mortality (for example fishing, turbine mortalities) would be considered (Rosenberg *et al*. 1994).

There exists clear guidelines for the establishment and application of reference points (ICES 1997/Assess:7, p. 4):

1) A reference point is an estimated value derived through an agreed scientific procedure.
2) Both limit reference points and target reference points should be used.
3) Management strategies shall ensure that the risk of exceeding limit reference points is very low.

A large number of reference points (both mortality rates and biomass levels) and their associated data needs are summarised in ICES 1997/Assess:7 (Table 4.2.1.1). The majority of reference points require information on several population parameters including age structure, growth, natural mortality, spawning stock size and recruitment size. The interpretation of some reference points relative to a theoretical stock and recruitment relationship is shown in Figure 4.2.1.1.

The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points (ICES 1997/Assess:7). To be consistent with a precautionary approach, limits should be defined in terms of mortality rates and spawning biomass levels (ICES 1997/Assess:7).

There are advantages and disadvantages to the establishment and application of mortality rate limits and spawning biomass limits (Rosenberg *et al*. 1994).

	Mortality limits	Spawning biomass limits
Advantages	Relate directly to the activity that can be controlled	Biomass is directly linked to recruitment
	Can be estimated from relatively limited data and information on life history characteristics	Provide a guide for management of stocks that are already depleted
	Can prevent stock depletion due to the long-term activity	Provides a seed stock for eventual recovery when adverse environmental conditions constrain abundance
Disadvantages	Do not provide protection for stocks which are already at low level	Difficult and extensive data to collect
	May require modification if environmental conditions and life history characteristics change	Risk of mis-estimation when a limited range of stock conditions is available
		May be mis-interpreted as the point at which the resource will collapse

The management strategies could involve mortality rate limits and spawner biomass limits applied singly or in combination (Figure 4.2.1.2):

- fixed harvest rate policy: removals represent a constant proportion of the recruitment,
- fixed escapement policy: all recruitment in excess of the spawning requirement is removed,
- floor policy: a fixed proportion of the recruitment is removed when recruitment exceeds the minimum spawning requirement.

The management strategies have consequences to yield and to spawning escapement. Use of fixed harvest rate policies has the least consequence on yield, i.e., fisheries are never closed but it has the most risk to the stock because the stock continues to be exploited even at low abundance. Continued harvesting at low abundance can have a destabilising effect which increases the risk of resource depletion (Beddington and May 1977). A fixed escapement policy has important consequences on yield because of fishery closures at low stock abundance but reduces the risk to the stock because at low abundance levels, spawners are protected. Floor policies have the greatest consequence to yield and the least risk to the stock. Lande *et al*. (1997) suggested that for a large class of population dynamics and a range of biological optimisation criteria (risk of resource collapse), the optimal strategy always involved a threshold population size above which all excess individuals are harvested. Thresholds are a necessary feature of harvesting strategies with the objective of minimising risks of resource depletion while optimising yields in variable environments (Lande *et al*. 1997).

4.2.2 Consequences of uncertainty

The greater the uncertainties, the greater the need to be precautionary (ICES 1997/Assess:7). Increased uncertainty renders optimal harvesting strategies more conservative and optimal threshold increases (Lande *et al*. 1997). F_{lim} and B_{lim} are reference points which should be avoided with high probability. There are uncertainties in the estimation of F_{lim} and B_{lim} as well as uncertainties in the assessments of the resource status relative to population abundance and exploitation. As a consequence of uncertainty, ICES (2000) defined precautionary reference points (F_{pa} and B_{pa}) to constrain exploitation to ensure a higher probability of not exceeding the limits. F_{pa} and B_{pa} are the main devices in the ICES framework for setting advice (ICES 2000).

4.2.3 Proposed limit reference points in data-poor conditions

The majority of reference points require information on several population parameters including age structure, growth, natural mortality, spawning stock size and recruitment size. The limited knowledge and particular population dynamics of American eel are a major obstacle to the derivation of reference points (Section 4.1). The wide distribution along the east coast of North America results in important differences in growth rates, age at maturity, and sex ratios. The mechanisms determining sex differentiation of animals are uncertain (growth rate, density, temperature, or a combination of factors). It is unclear how recruitment to freshwater occurs and whether there are regional stock and recruitment linkages. More importantly, there is little to no information on carrying capacity of habitat types for eels or what habitat variables determine carrying capacity. Natural mortality rates would vary with age and are likely high for the early life stages and decreasing with age and size.

Following the advice of ICES 1997/Assess:7, under data poor conditions, a mortality rate which provides 30% of the virgin (F=0) SPR is a reasonable first estimate of F_{lim} until further information is gathered. Considering uncertainties, a preliminary estimate for F_{pa} could be 50% SPR.

Estimates of spawning stock and recruitment for the American eel are not available. In the absence of such data, ICES 1997/Assess:7 suggested that biomass index series such as CPUE series or survey-based measures could be used to establish relative B_{lim} reference points. For example, the maximum survey index could be used as an indicator of virgin biomass and B_{lim} would be some value of that maximum level, such as 20% of max. The estimate of B_{pa} could be set at a value higher than B_{lim}, i.e. 50% of the maximum of the index series. At this time, no relevant indices of abundance of American eel exist on a continent-wide area. Consequently, no biomass reference points are proposed.

4.2.4 Preliminary reference points for American eel

Preliminary mortality rate reference points could be established across the entire species range. *Any reference points established should consider the following*:

- Given the difficulties in estimating and forecasting stock size, *fishing mortalities should remain below M (natural mortality)* (Walters and Maguire 1996),
- *Uncertainty in estimated population size increased B_{lim} (Lande et al. 1997),*
- *Ability to monitor compliance.*

Mortality rate reference points across the species distribution would ensure levels of escapement proportional to abundance in each stock area. Overall loss to spawning stock depends upon the number of years eels are vulnerable to the fishery. Reference exploitation rates would vary with region – higher in the south than in the north.

Preliminary values of F_{lim} were derived from a spawner to recruit analysis and provisionally determining F_{lim} at the F which generated 30% SPR. F_{pa} was estimated from the 50% SPR profile. These mortality reference points are estimated for eels aged one year and older. They could be calculated to include the elver stage but consideration for density-dependent regulation at the elver to yellow and silver eel stage would have to be considered (see Section 4.1).

The maturation schedule of eels is not well known, but female silver eels in northern areas are on average older than those in the south. The same is true for male eels. Some representative maturation schedules were examined to see the effect of these on the SPR solutions (Figure 4.2.4.1). Simple partial recruitment vectors considered in the example calculations assumed full and constant recruitment at a given age (age 3 years or age 12 years in the examples). This is a likely situation in some of the fyke net fisheries in tidal waters in eastern Canada which operate throughout the ice-free season, but would not be the case in other areas (Section 6.1).

An example calculation estimating F_{lim} and F_{pa} for eel with variable maturation schedules probably typical of northern area and southern area stocks is shown in Figure 4.2.4.2. The %SPR function is relatively insensitive to the natural mortality assumption (as seen by the width of the crescent profile) for the northern area assumptions but was more important for the southern area. F_{lim} to F_{pa} range was narrow (between F = 0.06 and 0.12) for the northern area stock and wider (between F = 0.11 and 0.32) for the southern area stock (Figure 4.2.4.2). The maturation schedule is particularly important in the estimation of F_{lim} and F_{pa} because this determines the number of years the animal is exposed to the fishery.

The reference points are also sensitive to the partial recruitment vector assumption. The partial recruitment profile would respond to management actions such as size limits on retained eels, mesh size limits, area restrictions, and seasons. In the second example, the effect of different partial recruitment vectors (fully recruited at age 3 years versus fully recruited at age 12 years) (Figure 4.2.4.1) but for a fixed maturation schedule (northern profile) is described. The F_{lim} and F_{pa} points increase as the age of full recruitment to the fishery increases. F_{lim} increased from 0.09-0.12 at fully recruited age 3 to 0.14-0.18 at fully recruited age 12 (Figure 4.2.4.3). F_{pa} increased from 0.06-0.07 at fully recruited age 3 to 0.08-0.118 at fully recruited age 12 (Figure 4.2.4.3). The higher reference point levels correspond to the reduced availability of animals to the fishery over their residence time in continental waters.

4.2.5 Limitations of F_{lim} method

The estimates described above are based on equilibirum conditions, i.e. no change in characteristics with abundance. Adding stock and recruitment to the model has an effect on yield calculations, i.e. yield declines with increasing spawning stock size (Hilborn and Walters 1992). Defining only F_{lim} reference levels can be dangerous because an F-based definition appropriate over a middle range of biomass levels may not be appropriate at the extremes of biomass. Also, the definitions set to prevent long-term decline of the stock do not increase the protection to the resource when it is in poor condition (Rosenberg *et al*. 1994).

4.2.6 Application of F_{lim} and F_{pa}

The estimation of F_{lim} and F_{pa} levels applicable to a stock are dependent upon information on the age and size composition, maturation schedule, and characteristics of the fishery itself including size selectivity and availability of life stages to the gear.

When the mortality factors on the stock are managed such that F equal to or less than F_{pa}, there should be a low probability that the realised mortality is not sustainable (ICES 1997/Assess:7). In the absence of B_{lim} and B_{pa} reference points, other measures of stock status would be used to assess compliance with the limit and PA points. These indicators would include size composition of the catch relative to unexploited areas, relative abundance of yellow and silver eels (when these are available for capture), condition factors, etc.

Table 4.1.1. General Life Cycle of American eel *Anguilla rostrata* with possible control and regulatory mechanisms.

Transition	Function	Control s (impacts)	Regulation
silver eel → egg	Fecundity-deterministic	Pollution *Anguillicola crassus*	Mating system (sex ratio)
egg→ glass eel/elver (pre-settlement)	Oceanographic-stochastic	Climate-ocean currents Tides, gyres Predation Foraging success Sargassum harvest	Unlikely except in near shore environments
	Oceanographic-depensatory	As above	Minimum larval production needed for dispersal to North American watersheds
elver → yellow eel (post-settlement)	Beverton-Holt saturating	Predation Passage Habitat fragmentation/loss Pollution Exploitation Climate/Ecosystem effects	Predation Dispersal Foraging success Territoriality Cannibalism
	Ricker-overcompensatory	As above	Increased importance of 1.Interference competition (space, food) 2. Cannibalism
yellow eel →silver eel	Beverton-Holt saturating	Passage Climate/Ecosystem effects Pollution *Anguilllicola crassus*	Dispersal Foraging success
	Ricker-overcompensatory	As above	Interference competition

Table 4.2.1.1. Commonly used reference points and their associated data requirements (source: ICES 1997/Assess:7).

Reference Point	Definition	Data requirements
Fishing rates		
$F_{0.1}$	Fishing mortality rate (F) at which slope of the yield per recruit (Y/R) curve is 10% of its value near the origin	Weight at age, natural mortality, exploitation pattern (F, partial recruitment vector)
F_{max}	F giving the maximum yield on a Y/R curve	Weight at age, natural mortality, exploitation pattern (F, partial recruitment vector)
F_{MSY}	F corresponding to Maximum Sustainable Yield from a production model or from an age-based analysis using a stock recruitment model	Weight at age, natural mortality, exploitation pattern (F, partial recruitment vector), stock recruitment relationship or general production models
$F_{30\%SPR}$	F corresponding to a Spawning Stock Biomass per Recruit (SSB/R) which is 30% of the SSB/R obtained when F = 0	Weight and maturity at age, natural mortality, exploitation pattern (F, partial recruitment vector)
F >= M	Empirical (for top predators)	M and sustainable F's for similar resources
F_{crash}	F represented by the tangent through the origin of a stock recruitment relationship	Weight at age, natural mortality, exploitation pattern (F, partial recruitment vector), stock recruitment relationship
F_{pa}	F precautionary approach, used to constrain mortality to ensure high probability of exceeding F_{lim} (mortality limit reference point)	Same as data required for other F reference point calculations
Biomass / Spawning Stock Levels		
B_{MSY}	Biomass corresponding to Maximum Sustainable Yield from a production model or from an age-based analysis using a stock recruitment model	Weight at age, natural mortality, exploitation pattern (F, partial recruitment vector), stock recruitment relationship or general production models
MBAL	A value of SSB below which the probability of reduced recruitment increases	Data series of spawning stock size and recruitment
$B_{50\%R}$	The level of spawning stock at which average recruitment is one half of the maximum of the underlying stock recruitment relationship	Stock recruitment relationship
$B_{20\%B\text{-}virg}$	Level of spawning stock corresponding to a fraction (for ex. 20%) of the unexploited biomass	Weight at age, natural mortality, exploitation pattern (F, partial recruitment vector), stock recruitment relationship
B_{pa}	B precautionary approach, used as constraint on mortality to ensure a high probability of exceeding B_{lim} (biomass limit reference point)	Same as data required for other B reference point calculations

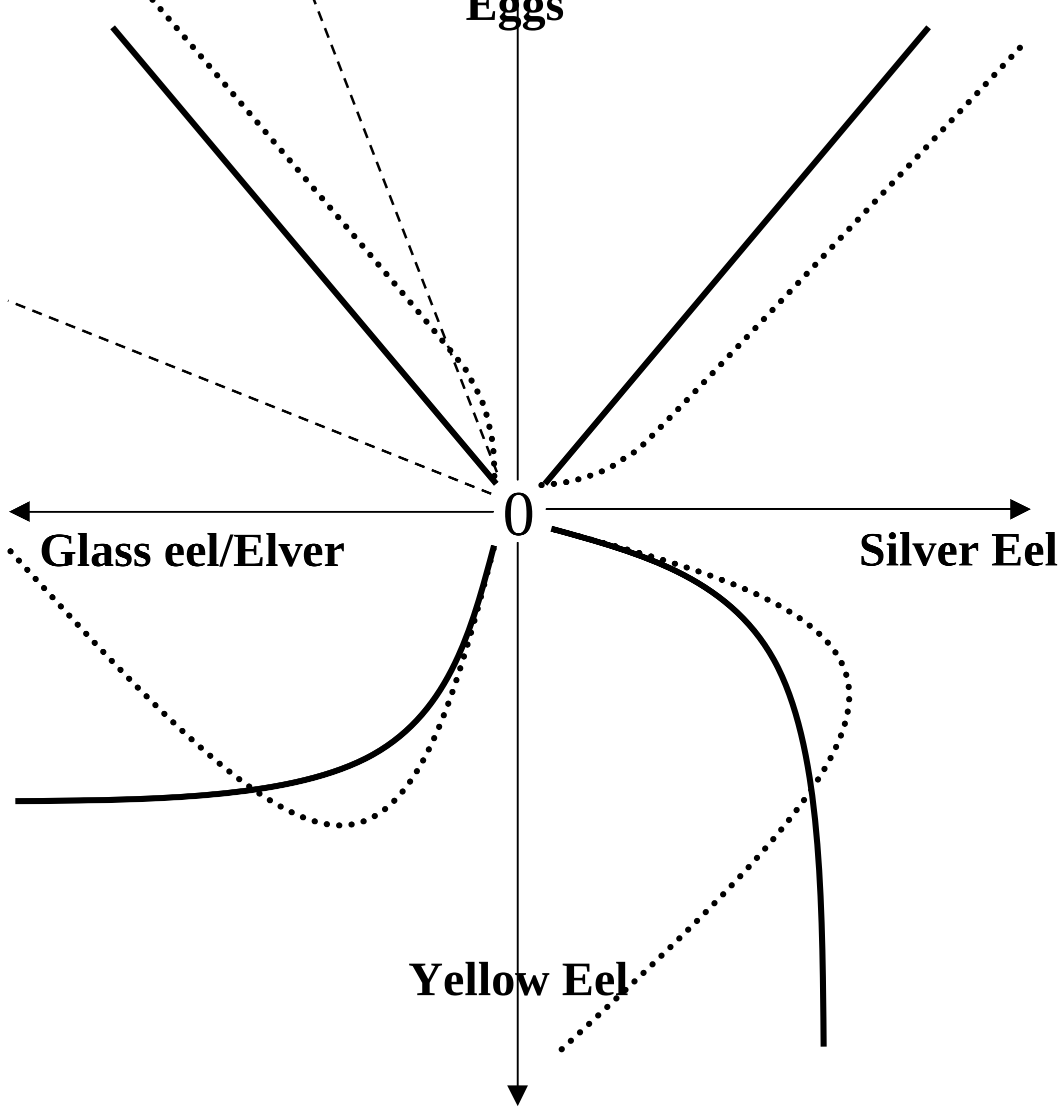


Figure 4.1.1. Paulik diagram of life cycle of American eel *Anguilla rostrata.* Critical life history transitions are represented for production rates of four stages: silver eel, egg, glass eel/elver (presettlement juvenile stages), and yellow eel. Null production for each stage occurs where axes intersect. Production of stages proceeds in a counter-clockwise manner from silver eels →eggs→elvers → yellow eels → silver eels. For the silver eel-egg transition, a dotted line presents scenario of depensation. Dotted lines also present an alternative scenario of density dependent regulation during elver-yellow eel and yellow eel-silver eel transitions. Dashed lines for the egg-glass eel/elver transition indicate the possible range and stochasticity of oceanographic effects on elver recruitment.

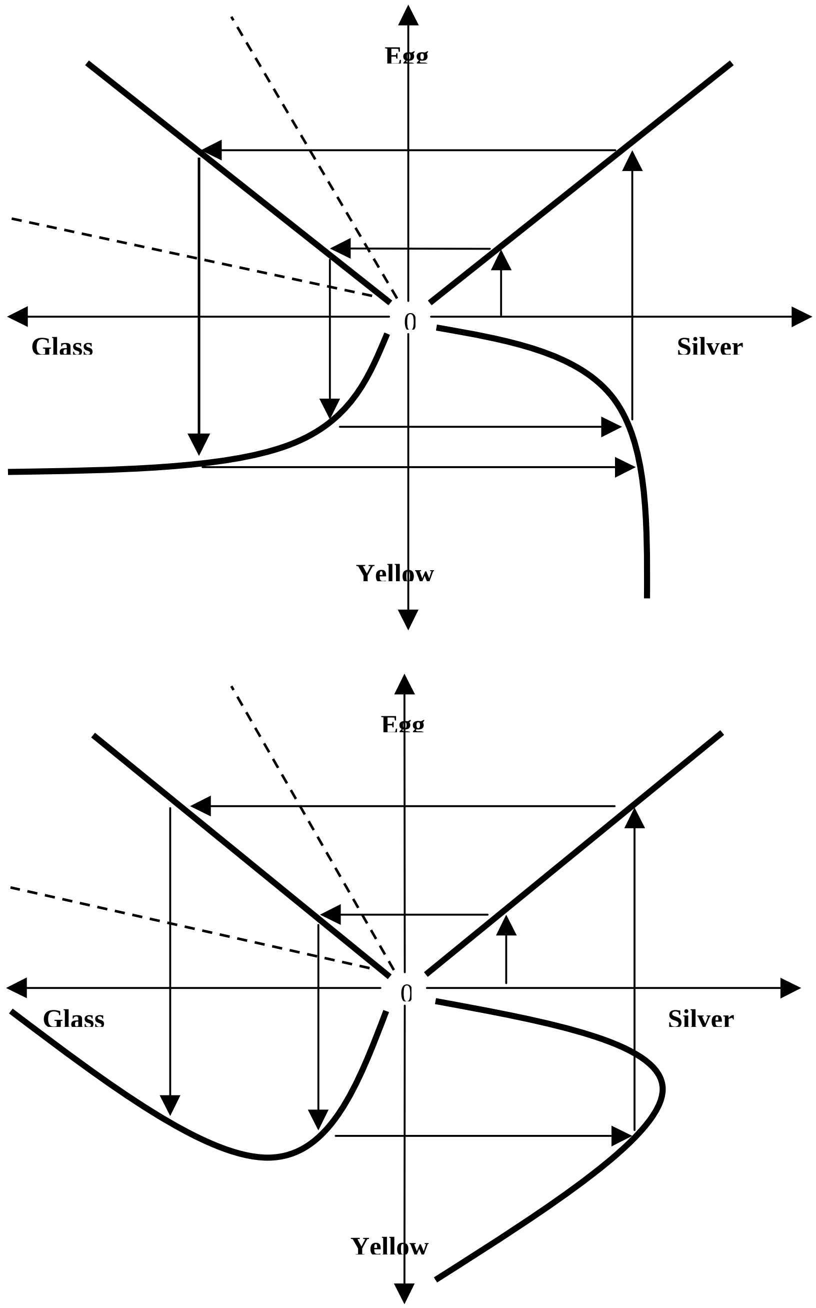


Figure 4.1.2.1. Production trajectory among life stages of American eel *Anguilla rostrata.* Production trajectory of stages proceeds in a counter-clockwise manner from silver eels →eggs→elvers → yellow eels → silver eels. Top panel and bottom panel show trajectories according to Beverton-Holt and Ricker transition functions in estuarine/freshwater habitats.

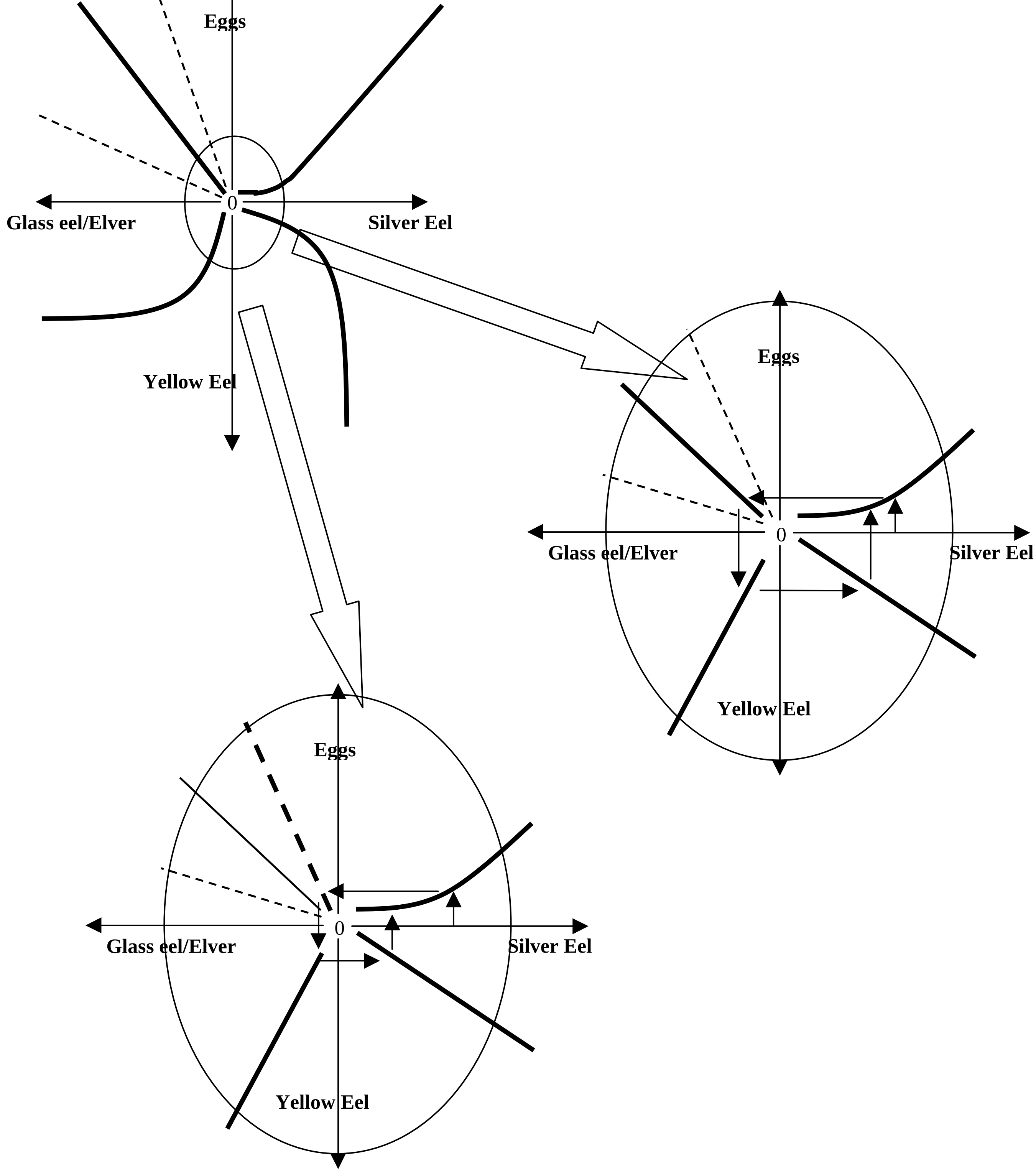


Figure 4.1.2.2. Production trajectory among life stages of American eel *Anguilla rostrata*. Production trajectory of stages proceeds in a counter-clockwise manner from silver eels →eggs→elvers → yellow eels → silver eels. Oval highlights portion of Paulik diagram corresponding to low silver eel production. Top breakout panel shows scenario of low spawning escapement, followed by a depensatory response. Bottom breakout panel shows combined scenario of early depensation and poor oceanographic conditions (shown by bold dashed line).

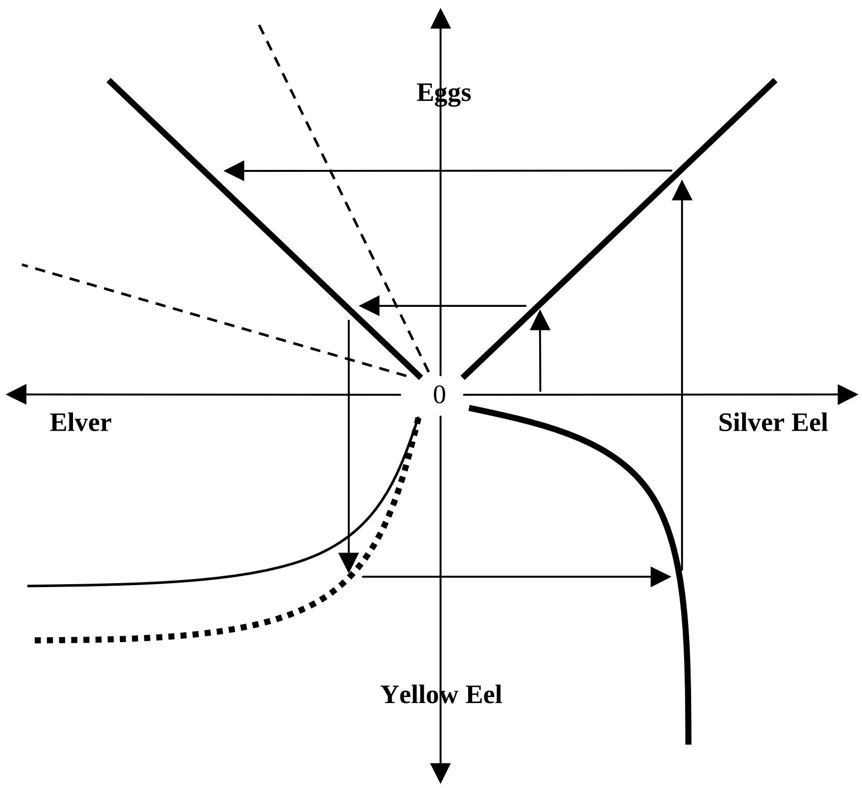


Figure 4.1.2.3. Production trajectory among life stages of American eel *Anguilla rostrata.* Production trajectory of stages proceeds in a counter-clockwise manner from silver eels →eggs→elvers → yellow eels → silver eels. Scenario is shown for increased estuarine/freshwater habitat (bold dotted line in lower left hand quadrant).

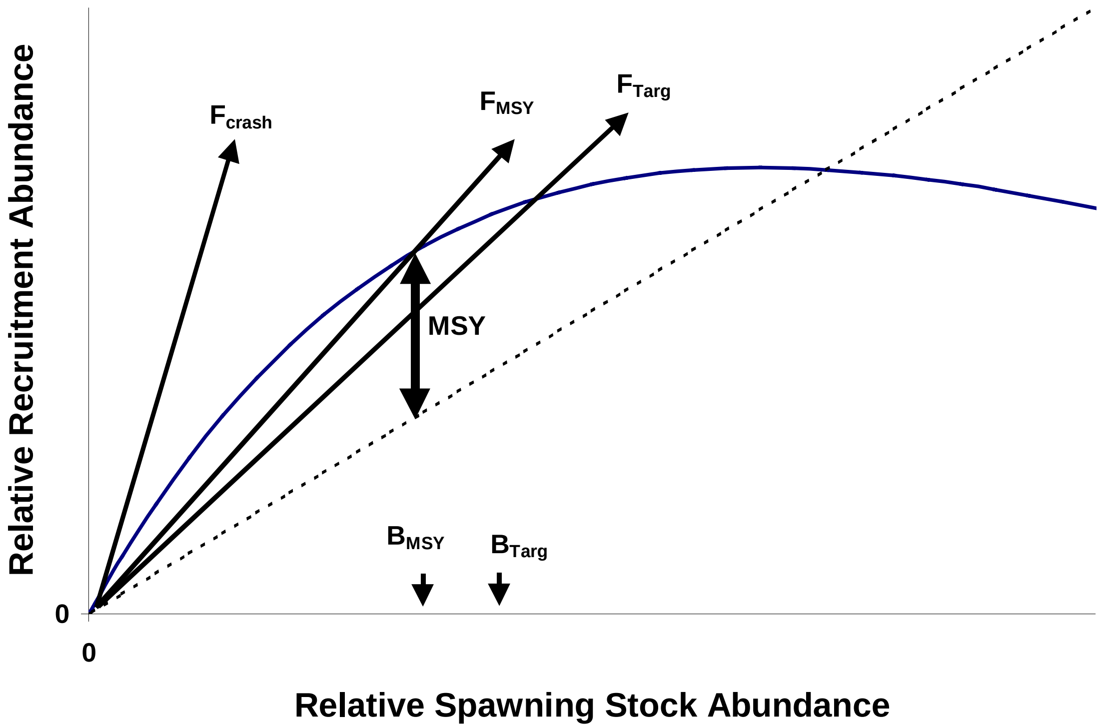


Figure 4.2.1.1. Position of some mortality rate and spawning biomass reference points relative to a theoretical stock recruitment relationship. The reference points are described in Table 4.2.1.1.

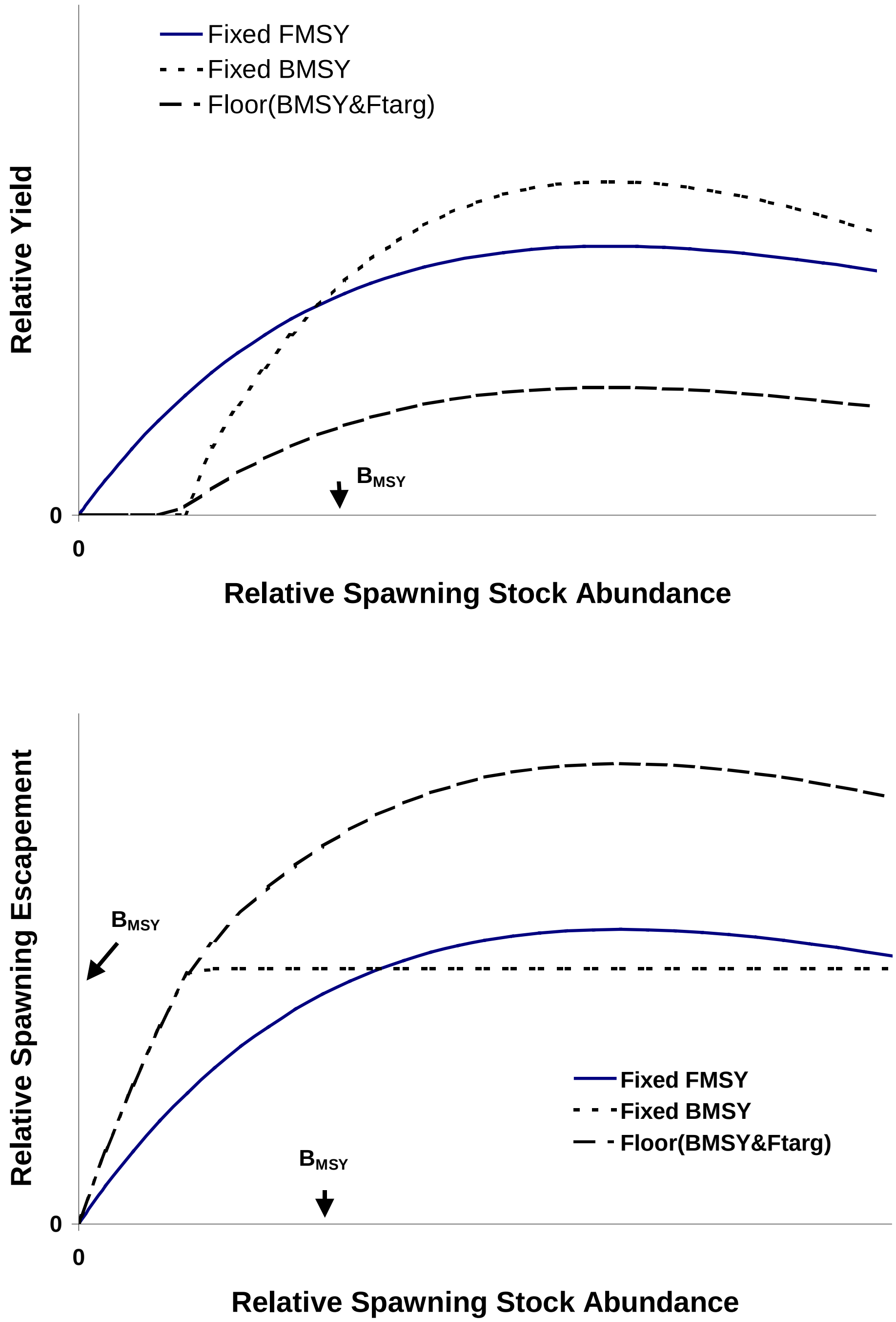


Figure 4.2.1.2. Effect on yield (upper panel) and on spawning escapement (lower panel) based on management policies using reference points. Fixed FMSY refers to managing on a fixed fishing mortality rate set at the fishing rate which generates MSY. Fixed BMSY refers to managing on a fixed spawning escapement (harvesting all recruitment in excess of BMSY) set at the spawning escapement which generates MSY. Floor refers to managing using BMSY and Ftarg when recruitment exceeds BMSY. The yield and spawning escapement plots were calculated using the theoretical stock and recruitment relationship in Figure 4.2.1.1.

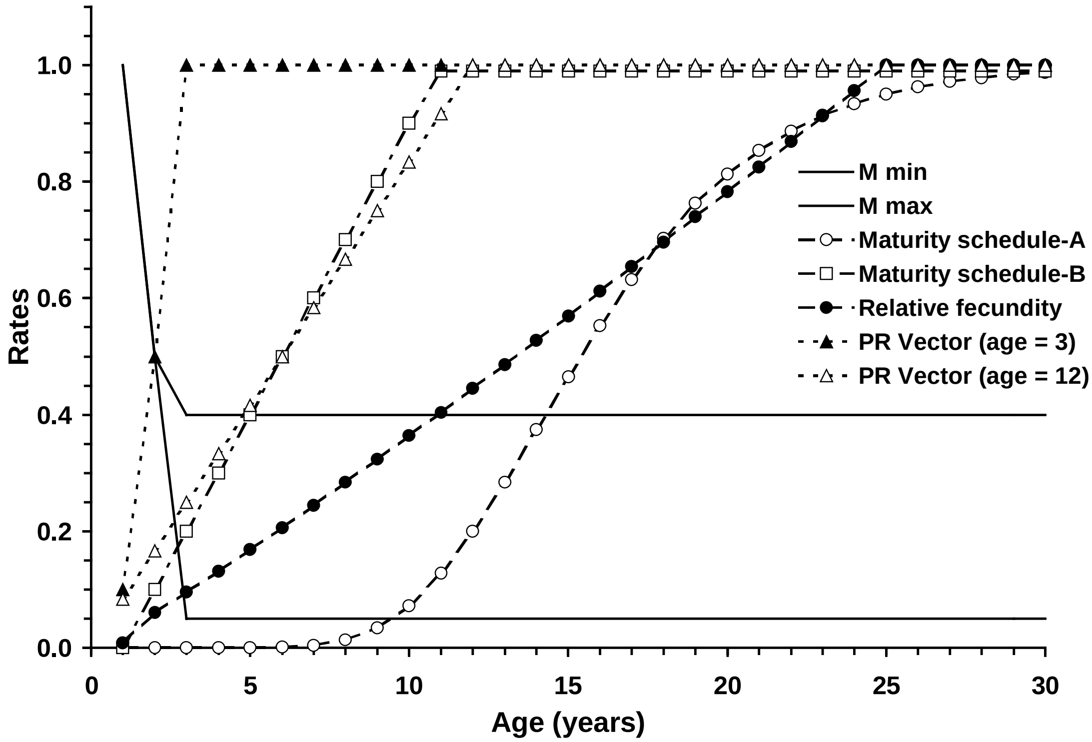
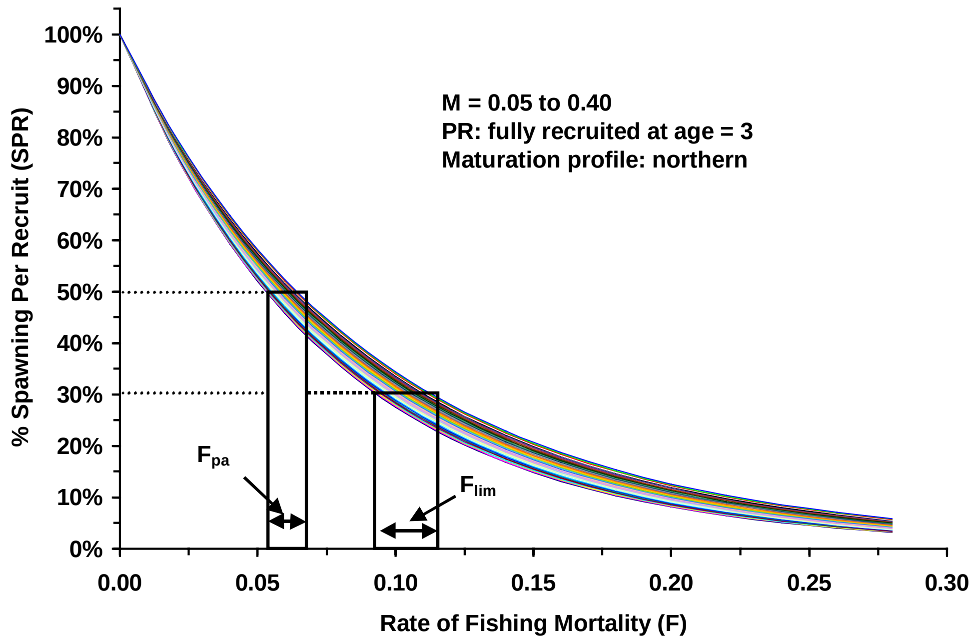


Figure 4.2.4.1. Input assumptions to the spawner to recruit modelling to estimate F_{lim} and F_{pa}. Maturity schedule refers to the proportion of the potential female yellow eels destined to metamorphose to silver eels. PR vector refers to the partial recruitment vector to the fishing gear. Maturation schedule A refers to a northern area stock and schedule B would be representative of a southern area stock.



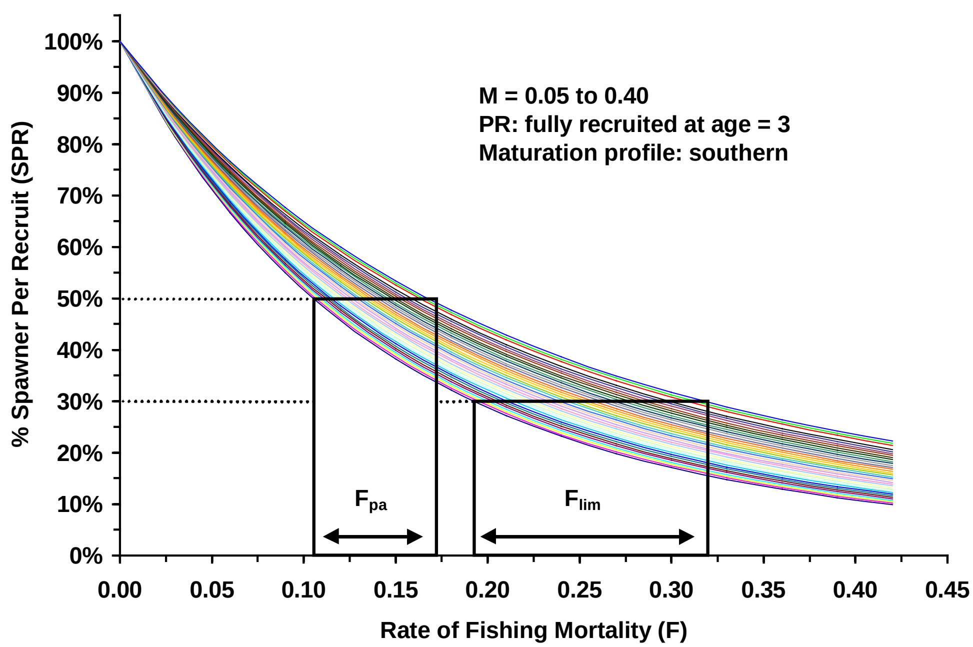


Figure 4.2.4.2. Estimated %SPR relative to F for the eel stock of the northern area (upper panel) and a southern area (lower panel) for varying assumptions of M. The estimated %SPR is eggs per R (adjusted for fecundity at length).

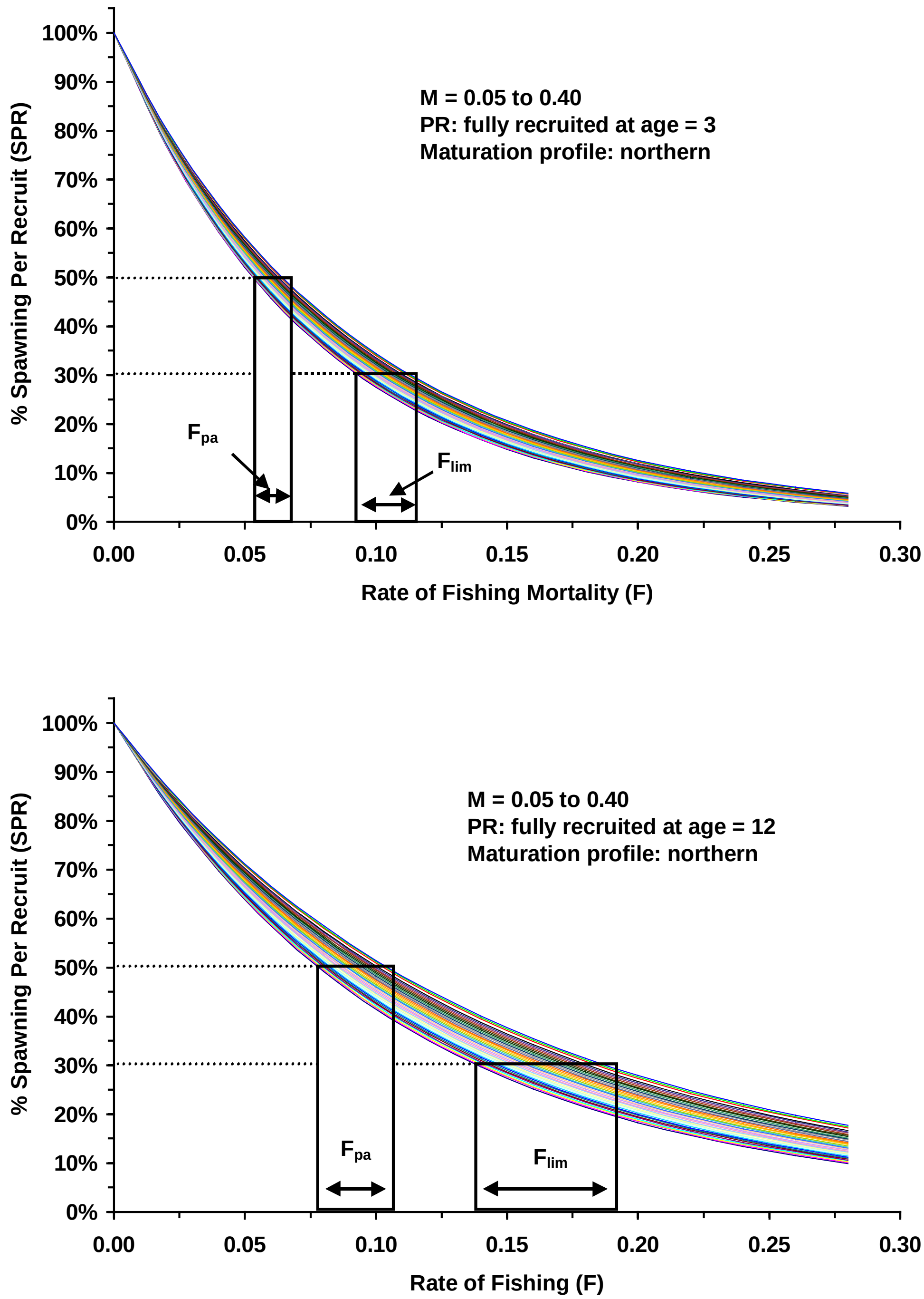


Figure 4.2.4.3. Estimated %SPR relative to F for varying assumptions of natural mortality (M) for the northern stock area with fixed maturity profile but different partial recruitment vectors.

5 MANAGEMENT UNITS FOR ESCAPEMENT TARGETS

5.1 Application of the Precautionary Approach

Genetic evidence suggests that the American eel is panmictic (Williams *et al*. 1973; Keohn and Williams 1978; Williams and Keohn 1984; Avise *et al*. 1986; 1990). The passive drift of eel leptocephali also suggests a panmictic population. Consequently, the number of recruits entering a river in a given year should not be related to the number of spawning eel that left the river in previous years, but should be related to the total number of eel from all geographic areas that spawned successfully. And to oceanographic conditions that affect their geographic distribution.

The most conservative application of the *Precautionary Approach* (see Section 4.2) to the development of management units for American Eel has several aspects. The *Precautionary Approach* would suggest that if recruitment declines were detected anywhere in the range, the most appropriate management would be to increase escapement of eel throughout the range. The *Precautionary Approach* would further suggest that, in case there are distinct geographic populations of American eel populations which have not been detected, escapement of eel should be increased more dramatically in the area where recruitment declines are detected.

5.2 Management Units

Substantial differences in life history parameters (growth, maturity schedule, sex ratio, etc.) exist within the eel's range e.g., Helfman *et al.* (1987), Facey and Van Den Avyle (1987). However, substantial differences in these parameters also exist within a single region and in some cases within a single river, resulting in no clear biological basis for identifying management units.

Geographic units are needed to provide a workable basis for management actions (e.g., increased escapement*). The Working Group felt that management of eel would ideally occur on a primary watershed basis.* This watershed unit would include all fisheries and other anthropogenic impacts that occur on an eel stock and would also assist in the maintenance of genetically distinct populations in the event that the species was found not to be panmictic.

The watershed approach poses two difficulties for implementation: 1) many small watersheds exist for which no information on eel is available to fisheries managers, and 2) in large watersheds (e.g., the St. Lawrence River) several fisheries management jurisdictions may be involved in the management of one eel stock.

The Working Group resolved that management units should be defined by the existing jurisdictions for eel management with the caveat described in Section 5.3. These jurisdictions include the Atlantic Coastal States in the United States of America, the Department of Fisheries and Oceans Canada, the Province of Québec, and the Province of Ontario.

5.3 Multi-Jurisdictional Eel Stocks

In areas where eels migrate through several jurisdictions during their life cycle the jurisdictions involved should cooperate to meet the management objectives for this eel stock. For example, in the St. Lawrence River, the Provinces of Québec and Ontario and the State of New York should cooperate on the management activities pertaining to the eels from the upper St. Lawrence River and Lake Ontario stock. Other areas where cooperation on eel management will be required include the Chesapeake Bay, the Hudson River, and the Delaware River.

5.4 Outside of Canadian/US Jurisdiction

American eel utilize a large geographic range including the east coast of North America as far north as Labrador. In addition, eel have been documented on the east coast of Central America, the islands of Caribbean Sea, and north-eastern South America, but little is known about their fisheries. *Additional information should be collected on these fisheries if they exist and the relevant fisheries management agencies encouraged to cooperate with actions to increase eel escapement (Section 7).*

6 MANAGEMENT ACTIONS FOR REQUIRED ESCAPEMENTS

With reliable data on recruitment, catches, effort, escapement, and the status of stocks it would be possible to consider long-term management, define reference points for fishing mortality and spawning stock biomass and coordinate management efforts across the geographic range of the American eel. However, the current data-starved position requires a pragmatic approach before such facts and figures are available.

In relation to fishery controls, there are various management options potentially available to fishery managers in Canada and the United States to achieve the reference points recommended in Section 4. Management jurisdictions within these two countries already have, to various degrees, management plans for the species in place as outlined below in Section 6.1. Section 6.2 outlines some of the more commonly used management options that may be implemented or strengthened to achieve the management goals.

6.1 Current Management Plans

Canada: Management plans for the American eel in Canada are implemented by the respective provincial governments in Ontario and Québec and by the federal government in the Maritime Provinces and Newfoundland (Table 6.1.1). The plans vary according to province and within New Brunswick and Nova Scotia, by the major watersheds, i.e., the Gulf of St. Lawrence (designated Gulf) and the Atlantic coast of Nova Scotia plus the Bay of Fundy (Scotia-Fundy). Only the provinces of Ontario and Québec exploit a common geographical segment of the eel population through their respective fisheries in Lake Ontario and in the St. Lawrence watershed.

Most of the catch (probably greater than 95 %) of American eel in Canada is taken by commercial fisheries, with the remainder harvested by recreational and aboriginal fisheries. Catch statistics for these latter two sectors are sparse.

United States: Prior to the development of the Atlantic States Marine Fisheries Commission (ASMFC) Fisheries Management Plan (the Plan), commercial eel fisheries were managed by the States according to regulations provided in Table 6.1.1. At its November 1999 annual meeting, ASMFC voted to approve the first Interstate Fishery Management Plan for American Eel (*Anguilla rostrata*) to be effective January 1, 2001. The Plan is a working document that describes the goals and objectives for the species, its current status, recent and historical trends, the ecological challenges affecting the species, management options and actions needed to reach and maintain the goals, and issues that need additional research support. In general, an ASMFC species management plan provides for the regulation of human activities that impact a species so that the population remains sustainable and viable, while also supporting the natural diversity of the ecological system(s) it inhabits.

The specific management unit for the Plan is defined as that portion of the American eel population occurring in the territorial seas and inland waters along the USA Atlantic coast, including all States and jurisdictions from Maine to Florida. The Plan also recognises that significant numbers of eel inhabit areas outside of ASMFC jurisdictional boundaries. These include watersheds in the Canadian Atlantic Provinces, upstream freshwater reaches that are managed by inland fish and wildlife agencies of ASMFC member States, and regional institutions such as the Gulf States Marine Fisheries Commission, as well as those waters within Native American Reservations where Tribal Governments have jurisdiction. Effective management of American eel in USA waters needs to recognise the interests of applicable Governments/agencies outside its jurisdiction, including nations both north and south of the U.S. to implement holistic methods in the protection and enhancement of this species.

Implementation of the ASMFC management program for American eel will be based on scientific advice provided by scientific staff of the state and federal agencies, as well as input from public hearings and an ASMFC Citizen's Advisory Panel. In general, management will strive for a long-term sustainable population, with a surplus to support recreational, subsistence, and commercial fisheries. Each State is responsible for implementing management measures and protecting American eel habitat within its jurisdiction to ensure the viability of the population segment residing within its boundaries.

<u>Recreational Fisheries Management Measures</u>: Currently there is an observed, but undocumented recreational fishery for American eel within the Atlantic coast States. The harvest rate is unknown, as is the discard mortality rate of American eel from recreational fisheries for other species. In order to minimise the chance of excessive recreational harvest, as well as circumvention of commercial eel regulations, states are required to establish a framework management program for recreational fishers, consisting of a 6-inch uniform size limit, possession limit not to exceed 50 eels, with no sale permitted by recreational fishers.

Commercial Fisheries Management Measures: For commercial fisheries, States shall institute licensing and reporting mechanisms to ensure that annual effort (including total units of gear deployed) and landings information by life stage (glass eel/elver, yellow eel, and silver eel) are provided by harvesters and dealers. Further, States are required to maintain existing or more conservative regulations, including gear specifications contained in Table 6.1.1, for all life stages. States with minimum size limits shall retain those size limits, unless otherwise approved by the ASMFC American Eel Management Board.

Management Measures in Federal Waters: The ASMFC American eel FMP further recommends that the U.S. Secretary of Commerce address and initiate controls over harvest and use of American eel in federal waters (3-200 miles offshore of the U.S. coast) that are not landed in states. Specifically, the Plan recommends that the Secretary of Commerce ban harvests of American eel at any life stage in the U.S. EEZ, but permit possession of up to fifty (50) eel per person for use as bait.

International Trade: In addition to existing channels for documenting exports, it is also recommended that the Secretary of the Interior proceed with listing American eel glass eels and elvers under Appendix III of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). An Appendix III listing in no manner prohibits the harvest of American eel at any life stage. The Appendix III listing will improve the regulation, protection, and control of glass eel in the lucrative, but largely undocumented international trade. The listing provides for monitoring and inspection at the port of departure and also at the port of arrival at the importing country through the use of a permit system. A CITES Appendix III export permit indicates that a legal harvest has taken place in accordance with the permit issuing authority.

6.2 Management Options

Possible management options which are discussed in more detail below include measures to limit exploitation by fisheries, protect and improve the productive capability of eel habitat, and enhance production through expansion of accessible habitat and the stocking of under-seeded or inaccessible habitat.

6.2.1 Measures to limit exploitation by fisheries

Measures to limit exploitation by fisheries will most often be site/area and circumstance specific; they will generally function by regulating the length of time that an individual eel will be possibly affected by the fisheries.

Prohibition of fishing: Prohibition of fishing can be life stage specific or area specific; for example, some areas (e.g., Pennsylvania) prohibit all commercial fishing, while others prohibit elver fishing or fishing in rivers. Many watersheds where eel production exists do not currently have fisheries (e.g., parts of Newfoundland and north shore of Québec) and, based on the conclusions of Section 2 on trends in recruitment and fisheries, it would be prudent to prohibit the introduction of new fisheries.

Total allowable catches/quotas: Ideally, application of total allowable catch/ quota restrictions requires knowledge of abundance and identification of escapement targets. Quotas put an upper limit on the total catch; however, with the diverse nature of the eel fisheries, it is difficult to envision how an individual quota on a panmictic stock would be shared and subsequently managed/enforced. Required data are not currently available for different life-stages of eel and therefore TAC approaches are probably not workable.

Gear controls: Controls on, for example, number, size, mesh-size, usage, and location of gear are already enforced in most American eel fisheries to control fishery mortality (Table 6.1.1). *Where they do not exist, they should be introduced and in other areas strengthened.*

Landing size limits: *Minimum* size restrictions could help to reduce excessive exploitation of yellow and pre-spawner eel. For example, minimum mesh size limits could be imposed for fyke nets and eel pots. Limits on *maximum* size would promote escapement of larger (that is: female) pre-spawners, but could also trigger increases in fishing effort aimed at smaller sizes.

Closed seasons: Closed seasons are currently used in some areas. They are commonly based on traditional or practicable fishing season or are primarily related to requirements to allow unhindered migration of other species such as salmonids. The effectiveness of fishing time controls is affected by temporal variations in eel activity and migrations, often as a result of changing environmental parameters. The timing of closed seasons must be related to local characteristics of eel and fisheries and has to primarily consider closure during periods of vulnerability. Some jurisdictions have implemented closed seasons for eel fishing unrelated to their vulnerability.

Closed areas: These could be locally effective, e.g., in preventing extension of fisheries (particularly for glass eel/elvers) into new areas or for protection of vulnerable glass eel/elver or silver runs. Alternatively, closed areas could be used to designate 'reserves' or 'refuges' where no exploitation would be permitted; such an approach is currently used in the management of eel stocks in New Zealand and could be applied to many watersheds of Canada and the United States where unfished eel populations are known to exist.

Licensing for fishermen and dealers: Licensing specific to eel for all fishermen and fishing gear and dealer licensing could help provide, via catch returns and market statistics, improved information for monitoring catches and compliance with targets. The quality of such information is currently often poor, but licensing of fishermen and gear, in conjunction with adequate enforcement of regulations, offers opportunities for controlling and monitoring fishing effort and, ultimately, fishing mortality.

6.2.2 Upstream and downstream passage

The effects of dams is the most significant factor affecting the upstream and downstream passage of eels where the structures are impassable or are shown to cause a significant delay in migration. There has been a long history of the successful use of upstream passage facilities as a cost effective means of mitigating the effects of hydro dams in Europe, New Zealand, and elsewhere. There are few sites along the Atlantic coast of North America where effective upstream eel passage facilities have been constructed. There appears to be considerable variability in the effectiveness of facilities installed for the upstream passage of eels. An effective management action would be to provide standards for the construction of fish passage facilities to maximise efficiency. In particular there is a need to specify a standard substrate that allows the passage of a variety of sizes. *It is recommended that fisheries management authorities develop a manual for the construction of fish passage ways for eels, and to identify characteristics of sites where these structures should be installed.*

Trap and transport methods also provide for an effective means of mitigating the effects of dams, particularly where consecutive dams are in close proximity. *It is recommended that this method of mitigating the effects of dams be considered when evaluating the needs for eel passage at specific locations.*

The downstream passage of migrating silver eels past dams remains problematical. The documented mortality rates caused by turbines at hydro dams is between 18% and 26.5%, although a higher mortality may occur with small turbines or where the head is high. These *mortality rates need to be included with fishing mortality rates to evaluate the overall impact on eel stocks.*

There are several management options available to mitigate the impacts of dams on downstream passage. These include the implementation of water management practices that might allow the spilling/overflow of water during the migration period for silver eels. *Where water intakes are present, the installation of screens to prevent entrainment should be installed, in conjunction with effective bypass systems*. It is recognised that some of these mitigation methods will be impractical at some sites. *It is recommended that fisheries managers consider mitigation methods for eel passage on a case-by-case basis. Evaluation should take into account that if there is increased production above dams provided by upstream passage facilities or stocking, then mortality rates caused by turbines may be offset by the increased production upstream.*

6.2.3 Transfers and re-stocking

Under the correct circumstances, transfers and stocking of juvenile eels to growing areas can be useful in increasing freshwater production and, by inference spawner escapement. Re-stocking may hence be considered as an alternative or additional practice to reductions in fisheries where increased spawner escapement is a requirement. Transfer of growing stock may also be useful in restoring locally depleted stocks, for instance upstream of dams or other barriers. Short range stocking programs (i.e., within watersheds or very local regions) are considered to be very much less risky than those involving transfers between watersheds or over greater ranges, which may contribute less well to spawner escapement and carry a higher risk of disease transfer.

The following are some key concerns relating to stocking:

- There should only be a presumption in favour of stocking where there is likely to be a positive, or at least no negative influence on overall escapement, taking into account all human-induced mortality. For example, stock should not be transferred into waters where there are likely to be impediments to emigration, for example upstream of hydroelectric turbines where mortality is known to be high, or above dams impassable to downstream migrants.

- Due consideration should be given to biodiversity issues–it should not be assumed that eels should be abundant in all waters, any more than any other species. There may be cases where other species take preference, or where eels would be an unwanted predator.
- The spread of parasites, diseases and non-native organisms that may be associated with eels should always be avoided.
- Consideration should be given to the possibility that stocking might mask declines in "wild" recruitment, leading to potential complacency over the true status of a wild stock. One possible means of avoiding this would be regular and structured surveys of mixed stocked and wild fisheries, which, in conjunction with documented stocking levels, might enable tracking of stocked cohorts within the system.
- Stocking should always be governed by the principles of adaptive management and accompanied by an evaluation program, so that effects can be measured and practices changed as necessary.

6.3 Conclusions/ Recommendations

Consideration must always be given to the fact that anthropogenic impacts on the American eel occur almost solely on prespawning stages of this animal and that those that survive all fisheries and downstream passage are destined to only spawn once.

Under a Precautionary Approach, considering the signals indicated in Section 2, it would be *prudent to not allow any increased exploitation and to prohibit the development of any new fisheries.*

It is recommended that fisheries management authorities provide a manual for the construction of fish passage ways for eels, and to identify structures where these characteristics of sites should be installed.

It is recommended that fisheries managers consider mitigation methods for eel passage on a case-by-case basis. Evaluation should take into account that if there is increased production above dams provided by upstream passage facilities or stocking, then mortality rates caused by turbines may be offset by the increased production upstream.

Table 6.1.1. Regulations governing eel fisheries in Canada and the U.S. Atlantic coast States in 2000.

Province/ State	Sector	Waters	Gear	Open season	Licence re-quired	Minimum size (cm) that may be retained	Comments
Ontario	commercial	inland	trap nets, hoop nets, hooklines & electro-fishing	year round for hooklines, others seasonal	yes	no size limit.	Harvest restricted by limiting new licenses, individual quotas and closed seasons, and buy-out have occurred. Harvest has remained well below quota.
	recreational	all waters	angling	year round	yes	20	No directed fishery.
Québec	commercial	St. Law-rence, fresh-water	longlines (38), eel traps (150)	year round	yes	20	
	commercial		pound net (28), hoop net (~4000)	1April - 30 Nov	yes	20	
	commercial		pound net (24)	year round	yes	20	
	commercial	marine & tidal	pound net (139)	1 Sept - 30 Nov	yes	20	
	commercial	inland lakes & rivers	all types	closed	yes	20	
	Native food	all waters	all types	year round	no	20	No known fishery.
	recreational	all waters	angling	year round	yes	20	No directed fishery.
Newfoundland	commercial	tidal & inland	pots	1 June/1July - 31 Oct	yes	20	Re-issuance (transfer) of eel licenses is not permitted other than through a transfer of complete enterprise.
	commercial		fyke nets	mid-Aug - 31 Oct	yes	20	
	experimental	head of tide	nets	20 June - 31 Aug	yes	<10	Elver fisheries, nine licenses with fixed quotas.
	recreational	tidal	pots	1 June/1July - 31 Oct	yes	20	
	recreational	tidal	spears		yes	20	

Table 6.1.1. (cont'd). Regulations governing eel fisheries in New Brunswick, Prince Edward Island, Nova Scotia and the U.S. Atlantic

Province State	Secto	Water	Gear	Open seaso	Licenc re-quire	Minimu size that be	Comment
New Gulf	commerci	tidal	trap	year	yes	38.1	In 1996 the minimum size in all Gulf NB eel increased from 20 to 38.1
	commerci	tidal	pots	year	yes	38.1	This fishery is legally open, but is
	recreation	tidal	spears	16 Nov-31	no	38.1	
	Nativ	tidal	trap	year	yes	38.1	
New Scotia-	commerci	tidal & inland	pots, eel nets, set lines & longline	year	yes	30	Commercial and recreational licenses frozen at Commercial licenses transferable, recreational transferable. Annual re-newal only to those previous year. Transfer of an existing commercial lic person is only permitted to a person registered and who participated in a commercial
	recreation	tidal	pots & longline	year	yes	30	
	recreation	inland & tidal, except spearing only in tidal	angling spearin	year	no	30	
	commerci	head of tide	traps, pots dip	1 Mar -31	yes	< 10	Elver fisheries, two commercial licenses with fixed qu quotas and individual river quotas). Elver fisheries on rivers not having other eel
	Nativ	tidal & inand	all	year	yes		Native fisheries are licensed, either as food, social or as
Prince Islan	commerci	tidal	trap	16 Aug - 15	yes	50.8	A 46 cm minimum size in effect on all PEI eel fisher 1970s, was raised to 50.8 cm 1998. In 1999, the o the trap-net fishery was changed from 16 Aug - 31 O 15
	commerci	tidal	spears	17 May - 30	yes	50.8	Spearing takes place at night with the aid of generato lights (flambeauing). Prior to 1993, the season was Aug. Prior to 1996, spearing was also permitted in the season was changed from 1 Apr - 30 Jun to 17 M

Table 6.1.1. (cont'd). Regulations governing eel fisheries in New Brunswick, Prince Edward Island, Nova Scotia and the U.S. Atlantic coast States in

Province/ State	Sector	Waters	Gear	Open season	Licence re-quired	Minimum size (cm) that may be retained	Comments
Prince Edward Island	recreational	tidal	spears	1 Jan - 31 Mar	no	50.8	Regulations specify a closing date of 30 Jun, but the season is closed on 31 Mar by administrative policy.
	Native	tidal	trap nets	16 Aug - 15 Oct	yes	50.8	
	Native	tidal	spears	17 May - 30 Jun	yes	50.8	
Nova Scotia Gulf	commercial	tidal	trap nets	1 Sep - 31 Oct	yes	50	In 1997 the minimum size in all Gulf Nova Scotia eel fisheries was increased from 20 to 50 cm.
	commercial	tidal	pots	1 Sep - 31 Oct	yes	50	
	recreational	tidal	spears	1 Sep - 31 Oct	no	50	
Nova Scotia Scotia-Fundy	commercial	tidal	pots, eel traps & weirs	year round	yes	20	Commercial and recreational licenses frozen at current level. Commercial licenses transferable, recreational licenses non-transferable. Annual re-newal only to those licensed in the previous year. Transfer of an existing commercial licence to a new person is only permitted to a person registered in proceeding year and who participated in a commercial fishery.
	commercial	inland	pots, eel traps & weirs	15 Aug - 31 Oct	yes	20	
	recreational	inland & tidal, except spearing only in tidal	angling & spearing	year round	no	20	
	recreational	tidal	pots	year round	yes	20	
	experimental & commercial	head of tide	dip nets, eel traps & pots	1Mar -31 Aug	yes	< 10	Elver fisheries, three commercial licenses and five experimental licenses with fixed quotas (license quotas and individual river quotas). Elver fisheries only permitted on rivers not having other eel fisheries.
	Native	tidal & inland	all types	year round	yes		Native fisheries are licensed, either as food, social and ceremonial or as commercial.

Table 6.1.1. (cont'd). Regulations governing eel fisheries in New Brunswick, Prince Edward Island, Nova Scotia and the U.S. Atlantic coast States in 2000.

Province/ State	Sector	Waters	Gear	Open season	Licence re-quired	Minimum size (cm) that may be retained	Comments
Maine	commercial	tidal & inland	fyke nets & weirs	15 Mar - 6 June	yes	none	Glass eel/elver fishery in effect, variable license fee by gear and by combination of gears. Pot mesh size 1.27cm x 1.27cm.
				6 June - 3 Mar		15.24cm	
New Hampshire	commercial	tidal	pots & nets		yes	15.24 cm	Coastal netting license required for nets and pots.
Massachusetts	commercial	tidal			yes	10.16 cm	Multiple license requirements.
Vermont	commercial	inland			yes	none	$500 electrofishing + $25 per crew member; Lake Champlain
Rhode Island	commercial	tidal			yes	15.24 cm	No fishing within 1/2 mile of fish ladder outlet.
Connecticut	commercial	tidal			yes	15.24 cm	Glass eel/elver fishery in effect. Dip net glass eel 3/1-5/31 with weekly closed periods.
New York	commercial	tidal	pots & nets		yes	15.24 cm	2.54cm x 1.27cm pot mesh or escape panel.
	commercial	inland	weirs, pots & set lines		yes	none	Pot entrance not > 5.08cm diameter.
Pennsylvania		inland				15.24 cm	Commercial fishng for eel prohibited.
New Jersey	commercial	tidal	pots & fyke nets		yes	15.24 cm	Glass eel/elver fishery closed. Multiple license options/fees for yellow eel fishery.
Delaware	commercial	tidal			yes	15.24 cm	
Maryland	commercial	tidal	pots		yes	15.24 cm	1.27cm x 1.27cm pot mesh or escape panel, limited entry.
Potomic River Fisheries Com.	commercial	tidal	pots		yes	15.24 cm	$75US per boat.
District of Columbia	commercial	tidal				15.24 cm	
Virginia	commercial	tidal	pots		yes	15.24 cm	Glass eel/elver fishery in effect, limited to two special permits. 1.27cm x 1.27cm pot mesh or escape panel, license plus gear fees, 2 year wait.
West Virginia	commercial	inland			yes	none	Except 5/15-6/30, jigging,snagging, snaring are prohibited.

Table 6.1.1. (cont'd). Regulations governing eel fisheries in New Brunswick, Prince Edward Island, Nova Scotia and the U.S. Atlantic coast States in

Province/ State	Sector	Waters	Gear	Open season	Licence re-quired	Minimum size (cm) that may be retained	Comments
North Carolina	commercial	tidal	pots		yes	15.24 cm	2.54cm x 1.27cm pot mesh, 20 eel limit per person per day.
South Carolina	commercial	tidal	pots & fyke nets		yes	none	Glass eel/elver fishery in effect, dip nets licensed. Gear permit required in addition to State license, 1.27cm x 1.27cm pot mesh.
Georgia	commercial	tidal	pots		yes	15.24 cm	3.81cm x 1.27cm pot mesh.
Florida	commercial	tidal	pots		yes	none	Glass eel/elver fishery in effect, limited to 3 special permits. 2.54cm x 1.27cm pot mesh.

Note: U.S. Atlantic coast States regulations subject to change. Escape panels of varying sizes by State are required.

7 COORDINATION OF MONITORING AND RESEARCH

In sharp contrast to assessment information collected for species populations with a relatively narrow range, the widespread spatial distribution of American eel is such that truly representative monitoring may not be achieved given current practices. Indications are that many life history characteristics vary throughout the range of American eel. The scale of impacts to eel life history varies widely from localized to oceanic levels. A coordinated, international effort to collect relevant data would allow better management advice to be given than is currently possible.

Therefore, *it is strongly recommended that an international commission be formed to organise monitoring and research.* The commission would serve as a clearing house for regular exchange of information regarding landings and resource status, and it would provide insight on research needs. The commission would conduct periodic workshops to facilitate international exchange of information and to suggest modifications to research and monitoring programs as required, and provide advice on management.

7.1 Monitoring

Agencies involved in monitoring should meet to discuss standardisation of methods for monitoring elver recruitment and silver eel escapement. At the very minimum, current monitoring of all life stages should continue as currently designed, and any additional emphasis should be placed on quantitative, rather than qualitative results. Consideration should be given to a watershed approach in the design of glass eel/elver recruitment surveys. Monitoring of silver eel escapement should reflect management strategies designed to assess compliance with reference point calculations. Sufficient numbers of silver eel should be sampled to determine ambient sex ratios at each monitoring site. Monitoring of yellow eel abundance and size/age frequency is recommended to describe the nature of relationships between elver and later life stage abundance, and to monitor sources of mortality.

7.1.1 Current monitoring: recruiting life stages

Canada: Two monitoring surveys presently exist for glass eels/elvers. One survey has occur ed since 1996 in the East River, Chester, Nova Scotia the other began in Prince Edward Island in 2000. The first of these occur in the Scotia-Fundy region of New Brunswick and in Nova Scotia (East River). Additional elver/juvenile sampling has recently been initiated (1996) on the north shores of the St. Lawrence River, Québec.

USA: The Atlantic States Marine Fisheries Commission has instituted a glass eel monitoring program. Beginning in 2001, every participating Atlantic coast state is required to conduct an annual survey of glass eel.

7.1.2 Current monitoring: yellow eel

Canada: Yellow eel monitoring exists in the upper St. Lawrence/ Lake Ontario system at Moses-Saunders Hydroelectric Dam and through long-term commercial fishing operations and trawl sampling. Monitoring at the Moses-Saunders site is considered to be of paramount importance to the understanding of the American eel resource regionally and range wide.

USA: Limited monitoring of yellow eel abundance exists in various State waters, however the ASMFC Plan (ASMFC, 2000) recommends that a comprehensive monitoring plan be established to address yellow eel.

7.1.3 Current monitoring: silver eel

Canada: Commercial catch and effort monitoring have been conducted in the St. Lawrence River since 1979. Silver eel monitoring programs have been initiated in 1999 in the Petite Rivière de la Trinité and Sud Ouest River (Section 2).

USA: No coordinated programs to assess escapement of silver eel are currently being conducted. However, the ASMFC management plan (ASMFC 2000) recommends the formulation of a coast-wide sampling program for American eel using standardised and statistically robust methods.

7.2 Research

7.2.1 International coordination of research

As recommended earlier, *an international commission should be formed to guide monitoring and research*. Canada and the United States are obvious participants, however inclusion of representatives from the Gulf States region of the USA, as well as *representation from Caribbean and Central and South American interests need inclusion in order to encompass the full geographic range as well as relevant issues regarding management of the species.*

A task of the proposed commission would be to identify and tabulate a list of current and recommended research activities. It is suggested that a survey of current research is conducted, and a database is maintained by the proposed international eel commission, to track active research initiatives. *The international commission should produce periodic reports of active research as recommended at the commission's annual workshops*.

7.2.2 Research priorities

7.2.2.1 Baseline landings and survey

Baseline landings and survey information is essential to proper management. Currently, total landings are not known with precision, nor can landings be differentiated by life stage, area (inland and coast), fishery type, or method in many places. Such information is essential to determine trends in recruitment, fisheries, stock abundance, and yield. *Surveys of elver-yellow eel-silver eel abundance are critical to understanding the nature of the relationship between life stage dynamics.*

In similar fashion, many basic life history parameters are unknown by life stage or location. Studies of basic eel biology including sex ratio, male and female growth rates, habitat preferences, predator/prey relationships; behaviour and movement during freshwater residency; oceanic behaviour, movement, location and spawning of mature eels; and examination of basic leptocephalus biology including nutrition, metamorphosis triggering mechanism, and mortality rate would be valuable in deciding proper management actions for the species.

Since eel inhabit freshwater and near-shore habitat for a large portion of their life span, research on the effects of pollution and accumulation or biological concentration of various xenobiotic contaminants on growth, maturity, and reproductive success would help provide insight into the management of the species.

Stock assessment and determination of current and sustainable fishing mortality rates and acceptable biomass levels are desirable aspects of any fisheries management plan, however such activities require well justified input parameters in order for resultant management advice to reflect biological reality and to resonate among the management community. In order for this concept to be realised for American eel, baseline data collections need to be improved throughout the range of the species.

7.2.2.2 Ecological evaluation of biological processes

Ecological evaluation of biological processes helps provide understanding from the empirical results of baseline studies. Such evaluations provide predictive value and insight towards population level response to management action. Latent population biology issues exist where determination of the existence of sub-populations or verification of panmixia requires further study. *Continuation of studies on genetic differences between American and European eel should include evaluations of migratory routes and guidance mechanisms for silver eel in the ocean, factors affecting larval and juvenile survival, mechanisms of exit from the Sargasso Sea, transport across the continental shelf, and impacts on elver recruitment and distribution due to climate change and oceanic circulation.*

Other necessary ecological information includes interactions of age, growth and natural mortality, particularly as confounded by sex, habitat, and possibly latitude. Primary needs involve age-at-entry of American eel glass eel into estuaries and fresh waters, mechanisms of sex determination, as well as evaluation of fecundity/length, fecundity/weight relationships from throughout the geographic range. Also, there is a need to determine natural mortality at specific life stages and within sizes of the yellow eel stage over the geographic range of the species. Determination of rates of maturation by cohort, and provision of a schedule of maturity is needed, as would be the development of an age/recruitment/migration chronology, using archived eel otoliths to determine cyclic patterns of eel abundance important to the understanding of oceanic influence and population trends.

Other ecological processes in need of evaluation include prey/predatory aspects of eel life history and their relative importance in the ecological energy flow of the systems they inhabit.

7.2.2.3 Research into anthropogenic impacts

Research into anthropogenic impacts on eel survival require evaluation. First, fishing losses, specifically those associated with fisheries for juvenile eel for use as bait, as well as impacts of elver fishing on abundance, distribution, and subsequent life history of later life stages within a watershed, need clarification. Second, as losses of American eel due to sources other than fishing are of concern, a database registry of barriers to passage, if available, would be helpful in determining impacts to ascending elvers due to habitat loss, or the degree of impingement/entrainment mortality for out-migrating silver eel. Continued research should 1) evaluate the impacts of upstream and downstream barriers to assess areas of extirpation and historical distribution, 2) model effects of hydroelectric facilities on eel population structure to provide a framework from which to judge the benefits of bypass improvement and mitigation options supporting key stock elements, and 3) evaluate downstream migration behaviour of eels through hydroelectric facilities as compared to migratory behaviour in un-impacted systems.

7.2.2.4 Research of basic methodological processes

Research of basic methodological processes as well as the exchange of ideas and experiences helps to improve results in baseline research. As such, *the objective evaluation and validation of various age determination techniques, by an independent study group, should evaluate the degree of precision and accuracy associated with each method.* Also, *future research should strive to investigate, develop, and improve technologies for American eel passage upstream and downstream*.

7.3 International Coordination of Management

Given that the suggestion has been to formulate an international commission to coordinate monitoring and research, logic suggests that this same group may be in a position to provide advice on international management. A management board of the proposed international commission could provide advice to those relevant nations on what, if any, agreements or alliances should be formed to manage shared resources. Three such modes of agreements become immediately obvious. The first being an agreement in North America dealing with American eel as a single species, with the relevant nations involved. The second being an agreement for multiple species which could involve several shared species in North America such as American eel, striped bass, American shad, and Atlantic sturgeon. The third mode of agreement could occur through either modification of the North American Salmon Conservation Organisation (NASCO) responsibilities to include European and American eel in addition to Atlantic salmon. Cooperation on eel management could be undertaken within NASCO, and separate North American and Northeast Atlantic commissions and NASCO’s relationship with ICES could be used to obtain regular scientific advice on Atlantic salmon and the two eel species.

Regular meeting of the management board would report on management strategies and proposed changes to management. Proposed changes would be derived through advice from technical committees, stock assessment committees, as well as advisory committees consisting of objective reviewers from various stakeholder groups including industry and academia.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

A review of available data confirmed either declining or neutral abundances of American eel in Canada/ USA and large declines in both recruitment of young eels to, and large fecund female silver eel escapement from the St. Lawrence River system which is situated near the northern end of the species range. Only one index demonstrated an increase in abundance. As well, there has been a major loss of habitat across the range and the possibility exists that oceanographic conditions may be affecting recruitment to the continent.

Eels are exploited at all life stages but the impact on overall silver eel escapement is unknown. Some areas in Canada/ USA remain unexploited but their contribution to escapement is unknown. Given that a panmictic hypothesis for the species has not been disproved, recruitment for northern areas is assumed to be dependent on total spawning stock size. Northern areas may also be more sensitive to larval dispersal mechanisms associated with oceanographic conditions.

Thus the Working Group concluded that reductions in habitat, declining or neutral trends in abundance, severe decline in abundance in northern areas, continuous exploitation and unknown oceanographic effects support the adoption of the *Precautionary Approach* in management.

8.2 Recommendations

Evidence from some areas of the American eel's range suggests that reductions in human-induced mortality (which includes both fisheries and hydro dam turbine mortalities) of yellow and silver eels may be required. However, the data to develop escapement biomass limits are not currently available but need to be developed and implemented as soon as possible. Consistent with the *Precautionary Approach*, the Working Group recommends that there be no increased exploitation in areas where exploitation occurs, no development of fisheries in areas where there is currently no exploitation, and efforts be made to reduce human-induced mortality wherever possible.

Also, effort should be made to improve data gathering (particularly catch information in Canada and USA as well as in the Caribbean and Central and South America), monitoring compliance with existing regulations and to implement appropriate regulatory measures where none exist.

Attention should also be given to resolving fish passage problems at obstructions that are limiting access to production areas, and contributing to mortality of migrating silver eels. There is a need to document and describe cost-effective technology allowing upstream and downstream passage and to develop manuals for locating and constructing fish passage at obstructions. Consideration should also be given to the trapping and upstream transfers of eels and minimally, the transfer of juveniles to under-populated habitat with free downstream access.

The Working Group resolved that management units should be defined by the existing jurisdictions for eel management, and in areas where eels migrate through several jurisdictions during their life cycle, that those jurisdictions should cooperate in meeting the management objectives for the stock. In addition to the collection of fisheries and catch information from the Caribbean and Central and South America, the relevant management agencies should also be encouraged to adopt a *Precautionary Approach* to the management of the American eel.

In recognition that the American eel is panmictic, future management will require international coordination. Fishery scientists require an international forum in which to annually exchange information, guide monitoring and research, facilitate workshops to e.g., evaluate and validate various age determination techniques, and to develop management advice (see Section 7.). Better information is required on catches, exploitation, life history parameters and demography for determination of current and sustainable exploitation rates and acceptable escapement biomass limits. As well, there is an important need to develop estimates of carrying capacity of eel habitat throughout the species range and to establish long term monitoring programs of recruitment and spawner output.

APPENDIX 1

Working Documents Submitted to the Working Group on North American Eels, 2000:

Doc No. 1 Caron, F. Overview of eel situation and recent research in Québec. Is the American eel declining everywhere in the St. Lawrence?

Doc No. 2 Caron, F. G. Verreault and E. Rochard. Estimation of the numbers of American eels (*Anguilla rostrata*) leaving the St. Lawrence watershed and their exploitation rate.

Doc No. 3 Verreault, G., P. Pettigrew, R. Tardif, G. Pouliot and J.-F Gaudreault. The exploitation of the migrating silver American eel in the St. Lawrence River estuary, Québec, Canada.

Doc No. 4 Verreault, G., and P. Dumont. Escapement of American eel from the Upper St. Lawrence River and Lake Ontario.

Doc No. 5 Robitaille, J.A., P. Bérubé, S. Tremblay, and G. Verreault. Eel fishing in the St. Lawrence River/Great Lakes system during the 20th century: signs of overfishing.

Doc No. 6 Jessop, B.M. Catches of American eel, by State, for the Atlantic and Gulf coasts of the United States.

Doc No. 7 Jessop, B.M. The status of American eel in the Scotia-Fundy area of the Maritime Provinces as indicated by catch and licence statistics.

Doc No. 8 Jessop, B.M., and C. J. Harvie. An update and reanalysis of the EPRI CPUE data.

Doc No. 9 Jessop, B.M., C.G. Hannah, J.W. Loder and S.P. Oakey. An exploratory model-based study of elvers drift across the Scotian Shelf and Gulf of Maine.

Doc No. 10 Harvie, C.J. Watershed areas and stream lengths in Nova Scotia, Canada.

Doc No. 11 Beak International Inc. The decline of American eel (*Anguilla rostrata*) in the Lake Ontario/ St. Lawrence River ecosystem: a modeling approach to the identification of data gaps and research priorities.

Doc No. 12 Weeder, J.A., and J.H. Uphoff Jr. Effect of changes in growth and eel pot mesh size on American eel (*Anguilla rostrata*) yield per recruit in upper Chesapeake Bay.

Doc No. 13 Oliveira, K., J.D. McCleave, and G.S. Wippelhauser. Regional variation and the effect of habitat on sex distribution of American eels, *Anguilla rostrata*.

Doc No. 14 Cairns, D.K., C.D. MacPherson, and M.C. Lister. A preliminary life table for the American eel in the southern Gulf of St. Lawrence, Canada.

Doc No. 15 Cairns, D.K., and M.C. Lister. Landings, population densities, and population trends of American eels in the Maritime Provinces of Canada.

Doc No. 16 Cassleman, J.M. and L.A. Marcogliese. Synchronous changes in abundance of the upper St. Lawrence River-Lake Ontario stock of the American eel (*Anguilla rostrata*): evidence for general species decline.

Doc No. 17 ASMFC. Atlantic States Marine Fisheries Commission American eel young-of-the-year recruitment survey.

Doc No. 18 Rosell, R. and M. Allen. Understanding the dynamics of the Lough Neagh eel fishery.

Doc No. 19 Rosell, R. and T. Potter. A precautionary management framework for the European eel (*Anguilla anguilla*).

Doc No. 20 Secor, D., W. Morrison, J. Steinbacher, and J. Baker. Stock dynamics of American eels in freshwater and brackish habitats of the Hudson River, New York.

Doc No. 21 Dekker, W. Insufficient spawning stock is a sufficient explanation of the recruitment decline in the European eel.

Doc No. 22 Knights, B. Executive summary - eel stocks & management in England & Wales.

Doc No. 23 Jessop, B.M. Annual and seasonal variability in the size and biological characteristics of the runs of American eel elvers to two Nova Scotia rivers.

Doc No. 24 Chaput, G. Biological reference points for American eel.

Doc No. 25 McCleave, J. Decadal-scale trends in proxies for atmospheric and oceanic circulation in the North Atlantic Ocean.

APPENDIX 2

References Cited

Anthony, V. 1982. The calculation of $F_{0.1}$: a plea for standardization. Northwest Atlantic Fisheries Organization, Serial Document SCR 82/VI/64, Halifax, Canada.

Atlantic States Marine Fisheries Commission (ASMFC). 2000. Interstate Fishery Management Plan for American Eel. Fishery Management Report No. 36. Washington, D.C. 79p.

Avise, J.C. G.S. Helfman, N.C. Saunders, and L.S. Hales. 1986. Mitochondrial DNA differentiation in North Atlantic eels: population genetics consequences of an unusual life history pattern. Proc. Natl. Acad. Sci. USA 83:4350-4354.

Avise, J.C. W.S. Nelson, J. Arnold, R.K. Koehn, G.C. Williams, and V. Thorsteinsson. 1990. The evolutionary genetic status of Icelandic eels. Evolution 44:1254-1262.

Barbin, G.P., and J.D. McCleave. 1997. Fecundity of the American eel *Anguilla rostrata* at 45^{o} N in Maine, USA. J. Fish Biol. 5:840-847.

Barse A.M., and D.H. Secor 1999, An exotic nematode parasite of the American eel. Non-native species management. Fisheries 24(2):6-10.

Beddington, J.R., and R.M. May. 1977. Harvesting populations in a randomly fluctuating environment. Science 197:463-465.

Beverton, R.J.H. and S.J. Holt. 1957. On the dynamics of exploited fish populations. Fisheries Investigation Series 2, Vol. 19. U.K. Ministry of Agriculture and Fisheries, London.

Boubée, J.A.I., C.P. Mitchell, B.L. Chisnall, and E.J. Bownman. (In press.) Factors regulating the downstream migration of mature eels (*Anguilla* spp.) at Aniwhenua Dam, Bay of Plenty, New Zealand. New Zealand J. Mar. Freshw. Res.

Busch, W.D.N., S.J. Lary, C.M. Castilione, and R.P. McDonald. 1998. Distribution and availability of Atlantic coast freshwater habitats for American eel (*Anguilla rostrata*). Administrative Report #98-2. USFWS, Amherst NY 28p.

Casselman, J.M., L.A. Marcogliese, and P.V. Hodson. 1997. Recruitment index for the upper H. Saunders hydroelectric generating station at Cornwall, Ontario, 1974-1995. pp 161-169 *In* Peterson, R.H. (Ed.). The American eel in eastern Canada: stock status and management strategies. Proceedings of eel workshop, January 13-14, 1997, Québec City, QC. Can. Tech. Rep. Fish. Aquat. Sci. No. 2196: v + 174p.

Castonguay M., P.V. Hodson, C.M. Couillard, M.J. Eckersley, J-D Dutil, and G. Verreault. 1994. Why is recruitment of the American eel, *Anguilla rostrata*, declining in the St. Lawrence River and Gulf? Can. J. Fish. Aquat. Sci. 51:479-488.

Couillard, C.M., P.V. Hodson, and M. Castonguay. 1997. Correlations between pathological changes and chemical contamination in American eels, *Anguilla rostrata*, from the St. Lawrence River. Can. J. Fish. Aquat. Sci. 54:1916-1927.

Dutil, J.-D., M. Michaud, and A. Giroux. 1989. Seasonal and diel patterns of stream invasion by American eels (*Anguilla rostrata*) in the northern Gulf of St. Lawrence. Can. J. Zool. 67:182-188.

EPRI. 1999. American eel (*Anguilla rostrata*) scoping study: A literature and data review of life history, stock status, population dynamics, and hydroelectric impacts. Electrical Power Research Institute Report TR-111873.

Facey, D.E., and M.J. Van Den Avyle. 1987 Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) - American eel. US Fish Wildl. Serv. Biological Report 82(11.74) U.S. Army Corps of Engineers, TR EL-82-4. 37 p.

Fahay, M.P. 1978. Biological and fisheries data on American eel, *Anguilla rostrata* (LeSueur). U.S. Nat. Oceanic Atmosph. Admin. Northeast Fish. Center Sandy Hook Lab., Tech Series Rep. No. 17.

Fernandez, J. and J. Vasquez 1978. Las pesquerias de angulas en la Provincia de holguin [American eel (*Anguilla rostrata* , Le Sueur) fisheries in Holguin Province, Cuba]. Rev. Cub. Invest. Pesq. 3(2): 48-61.

Greeley, J.R. 1932. Fishes of the area. A biological survey of the Oswegatchie and Black River Systems. New York Conservation Department, Biol. Surv. 6:54-92.

Helfman, G.S., D.E. Facey, L.S. Hales Jr., and E.L. Bozeman, Jr. 1987. Reproductive ecology of the American eel. Am. Fish. Soc. Symp. 1:42-56.

Hilborn, R. and C.J. Walters. 1992. Quantitative Fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall. 570p.

ICES 1997/Assess:7. Report of the Study Group on the precautionary approach to fisheries management. ICES 1997/Assess:7.

ICES 1998. European Eel. Extract of report of the Advisory Committee on Fishery Management No. 11. ICES, Copenhagen, Denmark.

ICES 2000. ICES cooperative research report No. 236, Report of the ICES Advisory Committee on Fisheries Management, 1999, Part 1.

Jessop, B.M. 1987. Migration eels in Nova Scotia. Trans Amer. Fish. Soc. 116:161-17

Jessop, B.M. 1997. An overview of European and American eel stocks, fisheries, and management issues. Pp. 6-20. *In* Peterson, R. H. (Ed.). The American eel in eastern Canada: stock status and management strategies. Proceedings of eel workshop, January 13-14, 1997, Québec City, QC. Can. Tech. Rep. Fish. Aquat. Sci. 2196: v + 174p.

Jessop, B.M. In press. Size and exploitation rate by dipnet fishery of the run of Ameriacanel (Anguilla rostrata) elvers in the East River, Nova Scotia. Dana 00:000.

Jessop, B.M. 2000. Estimates of population size and instream mortality rate of American eel elvers in a Nova Scotia river. Trans. Amer. Fish. Soc. 129:514-526.

Kelly, K.A. 1991. The meandering Gulf Stream as seen by the Geosat altimeter: surface transport, position, and velocity variance from 73° to 46° W. J. Geophys. Res. 96:12699-12709.

Kelly, K.A., and D.R. Watts. 1994. Monitoring of Gulf Stream transport by radar altimetry and inverted echo sounders. J. Phys. Oceanogr. 24:1080-1084.

Keohn R.K., and G.C. Williams. 1978. Genetic differentiation without isolation in the Amercian eel, *Anguilla rostrata*. Evolution 27:192-204

Kleckner, R.C., and J.D. McCleave. 1985. Spatial and temporal distribution of American eel larvae in relation to North Atlantic ocean current systems. Dana 4:67-92.

Knights, B. 1996. Risk assessment and management of contamination of eels (*Anguilla* spp.) by persistent xenobiotic organochlorine compounds. Chemistry and Ecology [Chem. Ecol.] 13(3):171-212.

Krueger, W., and K. Oliviera. 1999. Evidence for environmental sex determination in the American eel (*Anguilla rostrata*). Environ. Biol. Fish. 55:381-389.

Lande, R., B.-E. Sæther, and S. Engen. 1997. Threshold harvesting for sustainability of fluctuating resources. Ecology 78:1341-1350.

Larinier, M., and J. Dartiguelongue. 1989. La circulation des poissons migrateurs: le transit à travers les turbines des installations hydroélectriques. Bull. Français Pêche Piscicult. 312-313:1-90.

Liermann, M., and R. Hilborn. 1997. Depensation in fish stocks: a heirarchic Bayesian meta-analysis. Can. J. Fish. Aquat. Sci. 54:1976-1984.

Lorenzen, K. 1996. The relation between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. J. Fish Biol. 49:627-647.

Ludwig, D. 1998. Management of stocks that may collapse. Oikos 83:397-402.

Mace, P.M. 1994. Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. Can. J. Fish. Aquat. Sci. 51:110-122.

McCleave, J.D., R.C. Kleckner and M. Castonguay. 1987. Reproductive sympatry of American and European eels and implications for migration and taxonomy. Amer. Fish. Soc. Symp. 1:286-297.

Monten, E. 1985. Fish and turbines: fish injuries during passage through power station turbines. Vattenfall, Stockholm, 111p.

Nash, R.D.M, R. Berghan, A.D. Rijnsdorp, and H.W. Van der Veer. 1996. Exploration of the population dynamics of Irish Sea plaice, *Pleuronectes platessa* L. through the use of Paulik diagrams. J. Sea Res. 40(1-2):1-18.

Oliveira, K. 1999. Life history characteristics and strategies of the American eel, *Anguilla rostrata*. Can. J. Fish. Aquat. Sci 56(5):795-802.

Paulik, G.J. 1973. Studies of possible form of the stock and recruitment curve. Rapp. P.-v. Reun. Cons. Perm. Int. Explor. Mer 164:302-315.

Peterson, R.H. (Editor). 1997. The American eel in eastern Canada: stock status and management strategies. Proceedings of eel workshop, January 13-14, 1997, Québec City, QC. Can. Tech. Rep. Fish. Aquat. Sci. 2196: v + 174 p.

Porcher, J.-P. 1992. Les passes à anguilles. Bull. Français Pêche Piscicult. 326-327:5-14.

Richkus, W., and K. Whalen. 1999. American eel (*Anguilla rostrata*) scoping study: a literature and data review of the life history, stock status, population dynamics, and hydroelectric impacts. Electrical Power Research Institute, Palo Alto, CA. 1999. TR-111873.

Rosenberg, A., P. Mace, G. Thompson, G. Darcy, W. Clark, J. Collie, W. Gabriel, A. MacCall, R. Methot, J. Powers, V. Restrepo, T. Wainwright, L. Botsford, J. Hoenig, and K. Stokes. 1994. Scientific review of definitions of overfishing in U.S. Fishery Management Plan. NOAA Tech. Memor. NMFS-F/SPO-17. 45p.

Secor, D.H. and J. Rooker 2000. Is otolith strontium a useful scalar of life cycles in estuarine fishes? Fisheries Research 46:359-371.

Schmidt, J. 1922. The breeding places of eel. Phil. Trans. R. Soc. 211:179-208.

Smogor, R.A., P.L. Angermeier, and C.K. Gaylord. 1995. Distribution and abundance of American eels in Virginia streams: tests of null models across spatial scales. Trans. Amer. Fish. Soc. 124:789-803.

Taylor, A.H. 1995. North-south shifts of the Gulf Stream and their climatic connection with the abundance of zooplankton in the U.K. and surrounding seas. ICES J. Mar. Sci. 52:711-721.

Taylor, A.H. 1996. North-south shifts of the Gulf Stream: ocean-atmosphere interactions in the North Atlantic. Int. J. Climatol. 16:559-583.

Tesch, F.W. 1977. The eel. London: Chapman and Hall. 434 p.

Walters, C., and J.-J. Maguire. 1996. Lessons for stock assessment from the northern cod collapse. Reviews in Fish Biology and Fisheries 6:125-137.

Wenner, C.A. and J.A. Musick. 1974. Fecundity and gonad observations of the American eel, *Anguilla rostrata*, migrating from Chesapeake Bay, Virginia. J. Fish. Res. Bd. Can. 31:1387-1391.

Williams, G.C. , R.K. Keohn, and J.B. Mitton. 1973. Genetic differentiation without isolation in the Amercian eel, *Anguilla rostrata*. Evolution 27:192-204.

Williams, G.C., and R.K. Keohn. 1984. Population genetics of North American catadromous eel (*Anguilla*). pp. 529-560 *In* Turner, B.J. (Ed.) Evol. Gen. Fish. New York: Plenum.

APPENDIX 3

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APPENDIX 4

Definition of Terms Used in the Document

American eel life history:

Catadromy–Life cycle in which spawning occurs in the ocean, feeding and growth occur in estuaries and fresh waters, and adults return to the ocean to spawn. American eels are catadromous, and they die after spawning once.

Panmixis–Single breeding population over the entire species range, without population substructure. American eels are panmictic.

Recruitment–Immigration of young stages (elvers, young yellow eels) to continental (coastaland in land) waters.

Leptocephalus–The oceanic, pelagic larval stage of eels. This stage lasts several months in the American eel.

Glass eel–Small, transparent eel formed by metamorphosis of leptocephali. Metamorphosis occurs at sea, perhaps near the edge of the continental shelf. Glass eels are unpigmented elvers. Glass eels enter coastal waters and estuaries and many ascend rivers during winter and spring.

Elver - Small juvenile eel. Term some time used vaguely, but morely refers to the first year in continental waters.

Yellow eel - Juvenile eel residing for feeding and growth in continental waters. The color of the specimen is not diagnostic of this life stage. This stage typically lasts several to many years.

Silver eel - Sexually maturing eel migrating to the oceanic spawning area. The color of the specimen is not diagnostic of this life stage. Metamorphosis to this stage includes changes in body color, structure and physiology of the swim bladder, and structure and physiology of the eye.

Other Definitions

Dip net - An active capture gear consisting of a rigid frame filled with netting, firmly attached to a rigid handle and manually operated by a single person.

Fyke net - A funnel-shaped net designed to intercept and setain moving aquatic organisms. The net is of varying length from cod end to wing tips and is fitted with various size netting. For glass eels the net measures 0.3 cm (1/8 in) mesh square measure or less.

Hoop net - A stationary cylindrical net fitted with mesh that is placed at the bottom of a body of water. The gear includes wings or leads attached to the mouth of the net.

Pot - A cylindrical or rectangular trap with funnels that is baited. The gear is typically made of mesh.

Sheldon eel trap - A box trap with netted wings used to intercept and capture glass eels and elvers.

Spear - Historically the most widely known and used method of capturing eel. Often consists of a spatula-shaped center piece with multiple teeth on each side, each tooth having a single barb. A 3-9 m (10-30 ft.) long wooden pole is attached to this instrument for probing the soft muddy bottom, sometimes through a hole in ice or from a boat.

Trap - Passive gear similar to, but smaller than weirs. May have one or two wings facing upstream to capture descending silver eel. Wings, if present, do not block entire stream and the unit is considered portable.

Weir - A trapping device consisting of two wings extending from opposite shores of the stream running obliquely downstream and converging to form a funnel, to which is attached a box trap. As silver eels descend streams, the wings guide them into the box trap. This passive capture gear is semi-permanent, constructed of wood or other solid material, and usually blocks most or all of the channel.

APPENDIX 5

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