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Recovery Potential Assessment for the American Eel (*Anguilla rostrata*) for eastern Canada: mitigation options

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

This document addresses the Terms of Reference for the Recovery Potential Assessment associated with mitigation options for the threats to American Eel which were considered to be of medium or high level of concern. Mitigation options or alternatives to the activities are described and the contribution of these to recovery potential of American Eel are assessed. Commercial fisheries and threats associated with physical obstructions have clearly identifiable mitigation options and quantifiable potential for recovery. Habitat alteration threats can be managed with operational statements and mitigation options are defined in pathways of effects analyses for those activities not defined in operational statements. The threat of introduction and spread of the swim bladder parasite could be mitigated with existing policies on ballast water transfer and with established introductions and transfers oversight. The threats associated with ecosystem changes primarily due to non-native species invasions are more easily prevented than rectified once the species are established. Although climate variation is not considered a threat as such, low recruitment to Lake Ontario and the upper St. Lawrence River possibly associated with unfavourable oceanic conditions in the Atlantic Ocean may be offset by directed stocking programs of young life stages of eels from regions with abundant recruitment to areas with low recruitment but with productive and possibly vacant habitat.

Évaluation du potentiel de rétablissement de l'anguille d'Amérique (*Anguilla rostrata*) dans l'est du Canada : options d'atténuation

RESUME

Ce document porte sur les composantes du cadre de référence pour l'évaluation du potentiel de rétablissement liées aux options d'atténuation pour les menaces à l'anguille d'Amérique qui sont préoccupantes à des niveaux moyen ou élevé. Les options d'atténuation ou des activités de rechange sont décrites et les contributions de celles-ci au potentiel de rétablissement de l'anguille d'Amérique sont évaluées. La pêche commerciale et les menaces associées à des obstacles physiques ont des options d'atténuation clairement identifiables avec des potentiels quantifiables de contributions au rétablissement. Les menaces associées à l'altération de l'habitat peuvent être gérées avec des énoncés de fonctionnement et les options d'atténuation sont élaborées dans les diagrammes de séquence des effets pour les activités dont il n’y a pas d’énoncé de fonctionnement. La menace de l'introduction et de la propagation du parasite de la vessie natatoire pourrait être atténuée avec les politiques existantes en matière de transfert des eaux de ballast et par surveillance selon la politique des introductions et des transferts. Les menaces associées aux changements des écosystèmes en raison principalement aux invasions des espèces non indigènes sont plus facilement évitées que rectifiées une fois les espèces sont établies. Bien que la variation climatique n'est pas considérée comme une menace en tant que telle, les faibles recrutements dans le lac Ontario et le haut Saint-Laurent possiblement associés à des conditions océaniques défavorables dans l'océan Atlantique pourraient être compensés par les programmes de repeuplement visant des jeunes stades de vie des anguilles en provenance de régions de recrutement abondant vers les zones à faible recrutement mais qui contiennent des habitats productifs et possiblement vacants.

INTRODUCTION

Anthropogenic activities that can impact the American Eel in Canada are managed by three administrative regions of DFO in eastern Canada (Newfoundland and Labrador, Maritimes, Gulf) and by the provinces of Quebec and Ontario in their respective jurisdictions. The American Eel is identified as an Endangered Species under Ontario's Endangered Species Act (ESA), which prohibits the killing, harming, harassing, possessing, buying, selling, trading, leasing or transporting of this species (MacGregor et al. 2010). In 2006, DFO, the Ontario Ministry of Natural Resources and the Quebec Ministère des Ressources naturelles et de la Faune developed a draft integrated conservation plan to strengthen management of American Eel, to halt abundance declines, and to foster recovery of the population (Canadian Eel Working Group 2009). The draft management plan sets out actions with a focus on reducing mortality due to two known and significant sources (fishing, dams) while continuing to identify and establish mitigating actions for other sources of mortality.

The long-term goal expressed in the draft management plan is to rebuild overall abundance of American Eel in Canada to its level in the mid-1980s. The immediate and short term goal expressed in the plan is to reduce eel mortality from all sources by 50% relative to the 1997 to 2002 average. Although presently, the draft management plan has not been officially adopted by the partnering agencies, management actions consistent with the plan have been initiated in each jurisdiction.

The description of potential threats to the American Eel and an assessment of the threats with a level of concern scored as medium (threats that are likely to limit populations to low abundance and thus increase extinction risk) or high (threats that are likely to lead to substantial declines in abundance or loss of populations in the absence of mitigation) were provided by Chaput et al. (2014) for the five jurisdictions in eastern Canada (Table 1). Threats which scored a medium or high level of concern across all regions were: directed commercial fisheries for American Eel, and physical obstructions (loss of habitat). Region-specific threats, not shared across all regions, included turbine mortality and fragmentation of habitat (within the physical obstruction category), habitat alterations, introduction of the swim bladder parasite (*Anguillicoides crassus*), and changes in ecosystems mostly associated with non-native species introductions and spread (Table 1; Chaput et al. 2014).

The Terms of Reference for the Recovery Potential Assessment include an identification of feasible measures or alternatives to activities that are threats to the species and its habitat.

This document addresses the components of the generic terms of reference for recovery potential assessments (Fisheries and Oceans Canada (DFO) Science Advisory Schedule):

- TOR 21. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all feasible measures to minimize/mitigate the impacts of activities that are threats to the species and its habitat.
- TOR 22. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all reasonable alternatives to the activities that are threats to the species and its habitat (steps 18 and 20).
- TOR 23. Using input from all DFO sectors and other sources as appropriate, develop an inventory of activities that could increase the productivity or survivorship parameters (steps 3 and 17).
- TOR 24. Estimate, to the extent possible, the reduction in mortality rate expected by each of the mitigation measures in step 21 or alternatives in step 22 and the increase in productivity or survivorship associated with each measure in step 23.

The document is organized by threat category which scored medium or high in the assessment of Chaput et al. (2014) (Table 1). The first part for each threat describes the current management measures in place for managing the threat. The second part describes additional management measures or alternatives to mitigate the threat, assesses the potential for the mitigation action to contribute to recovery and describes whether the contribution to recovery can be measured within existing monitoring programs or programs which would be required to assess the contribution to recovery.

DIRECTED COMMERCIAL FISHERIES FOR LARGE AMERICAN EEL

Fishing for American Eel is an activity that can pose a threat to the species through direct mortality on individuals, by injuring animals not retained by the gear or selectively released, and by changes in population demographics and fitness associated with exploitation and stage selective fishing (Chaput et al. 2014). As a result of the semelparous nature of American Eel, all fisheries take place on immature individuals that have not spawned. Reference points in terms of biomass or fishing mortality rates have not been established for any eel fisheries in eastern Canada (DFO 2010b).

The American Eel (large eels) is currently fished commercially in all regions of eastern Canada with the exception of Ontario for which the directed commercial fishery was closed in 2004. Widely diverse gears are used in the fisheries (Table 2; Eales 1968). Total commercial fishery licences in eastern Canada are 1,089 (Table 2). Totals for deployed gear are not known. The majority of licences are for traps or pots which capture and hold the fish alive until the gears are fished and which would allow for the selective release of animals back to the water (Table 2). Longlines and set lines are also allowed in the fisheries of the DFO Maritimes Region, eels captured with these gear are alive when retrieved (Bradford 2013). Longlines have been used in the waters of Quebec (Tremblay 1997). Hooklines were historically used in the eel fisheries in Lake Ontario and there was one licence that permitted electrofishing (Stewart et al. 1997).

Commercial spearing is only allowed in the Nova Scotia portion of the southern Gulf of St. Lawrence (Table 2). There are also substantial recreational spear fisheries in all three Southern Gulf provinces. Some speared eels are able to free themselves from the spear and thus avoid capture. Post-spearing mortality in these animals due to puncture wounds is unknown. In previous decades in some areas, spearing accounted for very high proportions of the annual reported landings in the southern Gulf of St. Lawrence, and represented in many cases 100% of the landings in the winter fishery (Chaput et al. 1997). Management measures were introduced in some parts of the southern Gulf of St. Lawrence fisheries to prohibit the release of eels in the recreational spear fishery as a measure to prevent high-grading, i.e., the practice of discarding dead, injured, or small eels in order to provide room to catch larger eels within the daily bag limit (DFO 2010b).

Commercial landings of eel in eastern Canada were highest at about 1,200 t in 1971 and 1981 and have declined to about 500 t since 2000 (DFO 2010b; Cairns et al. 2014).

RESULTS OF MITIGATION ACTIONS TO DATE

The immediate and short term goal expressed in the draft management plan is to reduce eel mortality from all sources by 50% relative to the 1997 to 2002 average. In an assessment of progress on achieving these management objectives, DFO (2010b) concluded that:

- In Ontario and Quebec, the closure of fisheries and buyback of licences had resulted in reductions in total mortality of eels from fishing (measured as landings) of greater than 50% relative to mortality during 1997 to 2002.

- Declines in fisheries landings (by weight) of 27% were noted for the DFO Maritimes Region whereas average landings in DFO Gulf Region and in Newfoundland increased or remained unchanged. Decreased landings in the Maritimes may be confounded by issues of underreporting. Increased landings in the southern Gulf of St. Lawrence despite tightening of management rules are attributed to increased abundance of eels in this region.

MITIGATION OPTIONS

Cairns (2005) provided an overview of the potential mitigation options for fisheries to reduce exploitation rates and mortality of eels (Table 3). Those mitigation options, and a few others, are summarized below.

Reductions in effort

Reductions in effort to reduce exploitation and reduce mortality on eel can take the form of :

- Reductions in the number of licences
- Reduced number of gear units per licence
- Restrictions on gear configurations
- Shortened fishery season
- Minimum distances on gear spacing
- Establishment of berth systems for gear

The effectiveness of measures to reduce fishery effort depends upon the extent of the latent effort in the fisheries. Latent effort represents licences that are issued or gear types and quantities which are permitted but are not used. Harvest levels and exploitation rates will not be reduced if the licence that is retired is currently unused. In Gulf eastern New Brunswick in 2011, a harvest of 115 t was reported based on catch reports from 47 active licence holders, from a pool of 151 licences issued in 2011. In 2011 on PEI, 40 of 236 fyke net licence-holders had eel sales which were registered on the landings reporting system.

Eel mortality could be reduced by reducing the number of gears per licence. However, the proportional reduction in harvest might be less than the proportional reduction in gears per licence if fishers retain their best fishing sites, while abandoning the sites that fished less well (Cairns 2005).

Shortened fishery seasons may reduce mortality on eels and exploitation rates. Cairns (2005) provides an illustration of the potential consequences to reported landings of shifts in fishing season. In southern Gulf New Brunswick at that time the season was open from 1 April to 31 October and landings increased in spring, dipped in June, and then peaked in September. In this fishery, changes in fyke net fishing seasons that curtail fishing in the fall would be predicted to lead to greater harvest reductions than curtailments of open season in the spring and summer (Cairns 2005). The conclusions of this analysis are based on a pattern of landings and it assumes that effort is the same and at the maximum level permitted. However, the reductions in the seasons may displace effort which would have been deployed from an active period to a previously less active time of year.

Restrictions on gear configurations are in place in most areas, related to lengths of leaders and wings on fyke nets (southern Gulf of St Lawrence eastern New Brunswick), number of traps per gear, and mesh sizes. These measures are intended to limit the catch efficiency of gears, often to reduce bycatch of non-targeted species.

Cairns (2005) refers to increases in minimum spacing between gears as a possible mitigation measure to reduce harvest. Minimum spacing between fixed gears is 200 m in the Maritimes Provinces. The effectiveness of gear spacing measures on eel harvest depends, in part, on eel home range size. If eels have home ranges that are small relative to the minimum inter-gear spacing, then some eels might no longer be vulnerable to fisheries because their home ranges would not include gear. Literature values of eel home range vary greatly. Tagging studies on PEI indicated a maximum linear displacement of 350 m (D. Cairns, DFO unpubl. data), but daily movements of eels in another river in the Gaspe Peninsula were up to 4 km (Thibault et al. 2007). With such a wide variation in movement distances, it is difficult to assess the likelihood that some home ranges would not include eel gear, given a certain inter-gear spacing.

In areas where gears are currently deployed at the maximum permitted density, increases in the required inter-gear spacing would lead to a lower number of gears per watershed, and likely to a lower harvest. There are no field data to directly test the supposition that an increase in gear spacing requirements would reduce overall number of nets deployed (Cairns 2005). However, in Prince Edward Island, there are widespread anecdotal reports from fishers and from fisheries officers that indicate that good eel fishing grounds are fully subscribed under the current 200 m spacing rule. This implies that an increase in inter-net spacing requirements would decrease fishing effort, and likely harvest.

The use of berth systems, defined fishing areas assigned to individual fishers, may reduce fishing effort. Cairns (2005) indicates that based on anecdotal reports on P.E.I., some nets are installed on opening day only to hold the fishing site, and prevent other fishers from using it. In such cases, the possibility of placing nets in tidal waters anywhere in a broad geographical area, could lead to an artificial increase in fishing effort. Under a berth system, a fisher could delay setting nets for several weeks after the opening of the season, without fear of losing the fishing site to another. The extent to which eel fishing effort is artificially increased by the placement of nets to hold sites is not clear (Cairns 2005).

Establishment of size limits

In all the large eel fisheries of eastern Canada, except Quebec, there are minimum size limits of eels which can be harvested. Size limits differ among jurisdictions, being 20 cm minimum in Newfoundland, 53 cm minimum in the southern Gulf of St. Lawrence, and 35 cm minimum in the Atlantic coast of Nova Scotia and Bay of Fundy (Table 2). There are no size limits in the silver eel fishery of the tidal waters of the lower St. Lawrence River.

Minimum size limits have the objective of reducing the lifetime exploitation rates on eels prior to their emigration as silver eels. An exploitation rate of 10% in a strictly silver eel fishery equates to a loss of 10% of the silver migrating stock. An exploitation rate of 10% on yellow eels which are exposed to five years of a fishery before they migrate out of the area as silver eels equates to a loss of 41% of the potential silver eel production (Chaput and Cairns 2011).

Cairns (2005) illustrates how this management measure would be evaluated. Assuming that all legal-sized fish are large enough to be retained by the gear, the immediate effect of a change in minimum size on landings depends on the size structure of the population. In the illustrative example, an increase in minimum size from 35 cm to 55 cm would have resulted in decreased landings of 28% in Gulf N.B. and 16% in P.E.I., based on length frequencies from the catches (Cairns 2005).

The effect of increasing minimum retention size to reduce overall exploitation on yellow eels can have unintended consequences of shifting exploitation pressures to faster growing eels. Exploitation rate on larger eels may also increase if there is latent gear available which may be deployed by industry in an attempt to maintain catches at desired levels.

Minimum size limits would not be a good measure in silver eel fisheries. If such a measure was in place, the consequence would be to shift exploitation exclusively to larger silver eels, which phenotypically have higher fecundity per fish, and are likely to have better reproductive output.

Maximum size limits in eel fisheries have not received any consideration in Canada. If the maximum size limit is below the mean size at maturity, this measure would reduce harvests on larger silver eels (these being more fecund and more likely to reach the spawning grounds) but would shift all the fishing pressure on the yellow eel stages.

To reduce net overall exploitation on the stock, a slot could be considered which would limit the number of years eels would be available to the fishery, and reduce exploitation on silver eels.

Changing the fishing season may also be a means of reducing exploitation rates on silver eels, especially in areas where fisheries exploit both migrating eels and resident eels, and there is a seasonal distinction between movements of yellow eels within and among habitats and migration of silver eels out of the area.

The reliability of predictions of harvest reduction following changes in fishing rules depends on the quality of the data used in analysis; evaluations of the effects of minimum size changes reported by Cairns (2005) requires intensive sampling. Age and size distribution may fluctuate due to factors other than the fishery. Predictions of the effects of changing minimum size on harvest are probably fairly reliable in the period immediately after the new rules are implemented, because the age and size structure will have changed little since the analysis was done. In subsequent years, there is a chance that age and size structure will change more, so the reliability of the predictions will gradually diminish (Cairns 2005).

Harvest limits

The establishment of a quota, by individual fisher or for a region can be used to reduce the total number of eels harvested. When the quota is reached, the fishing season for all gears would be closed. This management measure can be used to control the absolute number or weight of eels harvested but not by itself the exploitation rate. If abundance declines, a fixed quota if fished would represent an increasing proportion of the stock.

Purchasing silver eels from the industry and releasing them alive to spawn is an option, akin to closing the fishery but with compensation, or using size limits with no size limit allowed for retention (Ontario Power Generation Inc. 2012). The value of that approach is that it would provide an opportunity to maintain indices of abundance which would otherwise not be available if the fishery was closed.

Compensatory responses of fishers to changes in management measures

Cairns (2005) stated that the analysis of predicted effects of management measures assumes that the introduction of new fishing rules will not lead to changes in fishers’ behaviour, other than the changes imposed by the new rules. However, fishers are likely to react to changes in fishing rules in ways that minimize the effects of the changes. For example, a fisher faced with tightened fishing rules may abandon fishing in places where catch rate is below average, and concentrate fishing effort in places where catch rate has been above average. Predictions of the effect of changing minimum size on harvest assume a constant age and size distribution. However, age and size distribution are influenced by fishing practices which may change with new fishing rules.

DIRECTED COMMERCIAL FISHERIES FOR GLASS EELS AND ELVERS

Fisheries on elver life stages occur in some rivers of the Atlantic coast of Nova Scotia and the Bay of Fundy (Bradford 2013) and an elver fishery has operated in Newfoundland since at least 2008. Elvers are captured and marketed alive. Reported annual landings of elvers between 1991 and 2012 ranged from 70 to 4,420 kg (Bradford 2013; Cairns et al. 2014); one kg of elvers represents approximately 5,500 individual animals (Jessop 2003).

MANAGEMENT MEASURES TO DATE

Elvers are defined in regulations as eels less than 10 cm (4”) in total length (Bradford 2013). The elver fishery in Scotia-Fundy began as experimental fishery in 1989 and there are presently nine licences, the same number of licences since 1998, four regular commercial licences and five experimental licences of which five are for aquaculture purposes only with no direct sale. The elver fishery was developed as an Enterprise Allocation fishery: licence holders have assigned fishing areas and (up to 2005) quotas of 1,000 kg per annum, with the exception of one licence where the assigned quota is only 300 kg. Quotas were since reduced by 10% for all licence holders. However the 10% of reduced quota can be fished if the elvers are destined for conservation stocking in Canadian waters (Bradford 2013).

On the Atlantic coast of Nova Scotia and the Bay of Fundy, elver fisheries were authorized on rivers that did not have established commercial fisheries for large eels and effort can be distributed among 82 named rivers/streams. However, the spatial separation between elver and large eel fishing locations has diminished in recent years. If elvers are the only stage which is exploited in the river or area where the fishery occurs, and if there are no density dependent compensatory effects on survival from reduced abundance, then the proportion of the elver runs harvested is the same as the proportion of the silver eels fished under a silver eel fishery only. Annual exploitation rates in elver dipnet fisheries in a small river in the Atlantic coast of Nova Scotia were estimated to have ranged from 12% to 59% during 1996 to 2012 with both market incentive to fish and elver run strength influencing the level of annual exploitation (R. Bradford. DFO, Unpubl. Data).

The elver fishery in DFO Maritimes Region is tightly controlled (Table 4). Licence holders have assigned rivers and quotas with daily hail-in and hail-out requirements. Daily landings are weighed by dockside monitoring and there is 100% mandatory weigh-outs for all elver shipments.

MITIGATION OPTIONS

Possible measures to reduce exploitation rates and fishing mortalities include reducing the harvests, i.e. reduce the quotas, and using annual area closures (rotational fishing) within the areas presently allocated for fishing (Table 5). Rotational fishing would permit periodic pulses of elver to recruit to rivers unimpeded by fishing, thus replenishing the standing stock of eels to the areas.

One management option which was in place in the glass eel / elver fishery of DFO Maritimes Region was the purchase of eels from the commercial fishery for the purpose of stocking (in Lake Ontario / upper St. Lawrence River for elvers). This management measure is currently used in Europe for relocation of glass eels and elvers from high abundance areas to areas of lower recruitment rates (ICES 2012). Although these animals are removed from the location of arrival to the coast, they are returned to the wild elsewhere and the survivors may contribute to future spawning stock of the species.

PHYSICAL OBSTRUCTIONS

The Physical Obstructions threat category encompasses threats associated with structures placed in or through water courses that restrict and impact the upstream and/or downstream movements of fish, change the habitat characteristics, and injure or kill individuals (Chaput et al. 2014). The obstruction of movements of fish can take many forms (barriers with or without upstream and downstream passage) and occur at many scales (large dams, culverts at road crossings) (Table 6).

MITIGATION OPTIONS FOR LOSS OF HABITAT

Pratt et al. (2014) summarize the extent of habitat which has become inaccessible to American Eel in eastern North America. Although eels are able to cope with certain natural and manmade obstacles to migration, upstream movement may be impeded or obstructed by large vertical barriers. The upstream passability of structures depends upon the height of the obstacle, as well as the slope and the smoothness of the barrier face being ascended, and the ability of eels to bypass structures decreases with size. Downstream passability considerations are also important. Fewer mortality rates and injuries are expected if eels are able to migrate downstream past dams through outlet structures and gates. The height of the dam, the structure of the spillway, and the presence of pools of considerable depth downstream of the dams are important considerations in minimizing injuries and mortalities during downstream passage.

Pathways of Effects (PoE) diagrams are available for activities which may impact fish passage (DFO 2013). A PoE is used to assess the type of cause-effect relationships that are associated with an activity and the mechanisms by which stressors resulting from the activity lead to effects in the aquatic environment (DFO 2013). In the PoE diagram each cause-and-effect relationship is represented as a line, known as a pathway, connecting the activity to a potential stressor and a stressor to an effect on fish and fish habitat. Each line in the pathway represents an area where mitigation measures can be applied to reduce or eliminate a potential effect (DFO 2013).

Removal of barriers

The removal of barriers and reconstruction of the natural bed of the river solves both the upstream and downstream passage issues. This provides the facilities for natural seasonal and annual migrations of life stages of eels. In some situations, the removal of a barrier and loss of a headpond may result in reduced production of eels because impoundments, especially small ones, have greater productive area for eels than the fluvial habitat. However the tradeoff between loss of productive lacustrine habitat and the gain associated with unimpeded access to a diversity of habitat has not been measured.

Construction of upstream and downstream passages

Solomon and Beach (2004) provide an extensive review of biological and non-biological design criteria for the design for upstream and downstream passage facilities for different life stages of eels. Descriptions of a number of facilities are provided including channel passes, pass-traps, pumped-supply passes, pipe passes, lifts and locks, and easements. Some of these are discussed further in an Ontario Waterpower Association report (OWA 2010).

MITIGATION OPTIONS FOR FRAGMENTATION OF HABITAT

Habitat fragmentation threats associated with a large number of small activities, such as improperly installed culverts at road crossings, are difficult to quantify. In the case of road crossing structures, particularly culverts, the upstream passage may be restricted due to poor installation (overhang of structure creating a dropoff), excessive length of structure, steep gradients and strong currents which may exceed the burst swimming capacity of eels. An analysis of the pathways of effects associated with the threat of fragmentation of habitat include the placement of materials or structures in water (PoE 10), flow management (PoE 16), and fish passage issues (PoE 17) (Coker et al. 2010) (Table 7).

In most provinces, guidelines are in place for the installation of stream crossings with the objective of ensuring that new or refurbished facilities meet current fish passage objectives in the guidelines (for example Gosse et al. 1998; New Brunswick 2010). However, compliance with these guidelines is often incomplete.

MITIGATION OPTIONS FOR TURBINE MORTALITY

Eels that pass through a turbine may be injured from a blade-impact, as a result of pressure changes (cavitation), and velocity differences (shear forces), with blade-impact being the most important (OWA 2010). Turbine mortality is positively related to eel length and inversely related to turbine blade spacing; consequently large female eels are at greatest risk of turbine mortality and injury. There may also be delayed turbine related mortality associated with injuries. Concerns about turbine mortality may also be associated with hydrokinetic turbines which operate using un-modified water flow (such as tidal power and in large rivers in the absence of dams).

A number of options have been considered for mitigating turbine mortality. Most have been discussed in OWA (2010) and in Greig et al. (2006) and are summarized below (Table 6).

Turbine design

Turbine mortality is reported to be positively related to eel length and inversely related to turbine blade spacing. No full scale case studies are available to date regarding the use of alternative turbine designs to minimize the impacts to American Eel (OWA 2010). Small-scale prototypes of “fish-friendly” turbines with a helicoidal propeller have been tested and reportedly achieved over 98% survivorship using eels of length proportional to full-size models (OWA 2010). However, the fish-friendly turbines produced only 20% of the power output of a propeller turbine of the same size (OWA 2010). A very low head (VLH) turbine consisting of a one-piece turbo-generator group installed at an angle to the current was tested in France and achieved a 92% survival rate of silver eels. The results of the tests are promising for run-of-the-river waterpower facilities with very low head but retrofits may not be feasible (OWA 2010). Alternate turbine design considerations are feasible in new installations but much more difficult in retrofit situations.

Water management / dam operating plans

Water management could be considered for passing silvering eels downstream. These actions generally involve temporary shut-downs to facilitate ‘spillage’ during the migration period (OWA 2010). Possible shutdown strategies include: continuous shutdown during the migration season, nightly shutdown during the migration season based on the negative phototactic behaviour of eels, shutdown during rain events that increase flow and/or turbidity and concentrate migration peaks on small streams, shut-downs triggered by knowledge of environmental cues that trigger migration on a specific river, and automated identification of eels entering an area upstream of the turbines triggering shut-down (OWA 2010). These strategies have different information requirements (for eels and specific to the area) and different operational consequences. Carr and Whoriskey (2008) demonstrate the complexity, and lack of predictability in eel behaviour at a dam associated with time of day, rainfall, and amount of spillage. The extent that water management strategies can contribute to recovery of American Eel depends upon the proportion of migrating eels which can be directed away from turbine intake and into alternate downstream passage routes. These are very likely to be site-specific.

Barriers

Fully safe downstream passage of eels can presently only be provided through avoidance of turbine passage (OWA 2010). Devices developed to prevent the passage of eels through turbines include physical barriers, behavioral barriers, and bypasses.

Physical barriers

Ontario Waterpower Association (OWA 2010) indicated that of eight types of physical barriers for fish-diversion developed, only two could be recommended as Best Management Practice methods; fine mesh screens and high flow screens.

Fine mesh screens, installed upstream from the water intake, or at the level of the trash rack, prevent fish passage with the intention of directing them toward a bypass. Fine mesh screens have not been frequently used in Canada, having been installed at two power stations located on the north and south shore of the St. Lawrence Estuary in Quebec, and were assessed at having achieved 100% diversion efficiency (OWA 2010). The size of the facility is a critical factor in the applicability of screen-use. Screens are not recommended for large facilities such as Iroquois dam or Moses-Saunders dam, or where debris loading exceeds the capacity of the cleaning device (OWA 2010).

High flow screens, also called Modular Incline Screens (MIS), form an inclined plane in the penstock directly upstream from the turbine to lead fish to a surface bypass, or some other adjoining bypass system (OWA 2010). Passage efficiencies of 80-100% have been reported (OWA 2010).

Behavioural barriers

Behavioural devices that attract fish are usually more effective than those that induce an avoidance reaction because attraction can be coupled to a bypass, whereas avoidance does not assist in an eel locating a bypass (OWA 2010). These systems are generally less expensive (installation, operation and maintenance) and non-intrusive compared to physical barriers and three devices that show promise are light, infrasound, and hybrid devices (OWA 2010).

Underwater lights have a repulsive effect on eels because they are negatively phototactic, however, diversion efficiency results have been generally poor, and with a wide range of results generally under 75% for downstream migrating eels (OWA 2010). A full scale test of the diversion efficiency of a light array was completed on the St. Lawrence River by New York Power Authority (NYPA) in 2002 and the maximum diversion efficiency achieved was 85%, however, this value decreased to 58% when considering the estimated proportion of daylight migration of eels on the St. Lawrence River (OWA 2010). Patrick et al. (1982, 2001) conducted field studies and laboratory tests followed by field trials at the Saunders generating station facility on the St. Lawrence River near Cornwall, Ontario to determine whether strobe lights could be used to deter eels from entering a turbine. Both investigations showed a strong avoidance of white strobe light and a reduction of eel movement of between 65% and 92%. In the laboratory and field trials eels avoided low light intensities for all strobe flash frequencies tested, and showed no behavioural adaptation to the light source over a prolonged time period. All size classes of eels were repelled, but effectiveness appeared to be reduced for smaller eels.

Although lights are unlikely to ever divert 100% of eels from turbine intakes, and are not applicable to all sites, they are considered as a best management practice (BMP) because of the potential to couple lights with other behavioral barriers and/or BMPs (OWA 2010).

Bypasses

A bypass is a flushing or diversion channel, or any other structure (e.g. spillway) specifically designed for fish to avoid passage through the powerhouse. Efficiency of bypass-use is generally under 60% for eels when used alone or in combination with physical barriers with large spacings (OWA 2010). Eels seem to find the bypass randomly and the installation of several bypasses is recommended because of the lack of guiding efficiency of devices used for eels (OWA 2010).

Trap and transport

Trap and transport is a bypass system. It involves trapping eels above a facility and transporting them around the facility and releasing them downstream In the case of multiple barriers, the fish could be transported around all the facilities before release.

A yellow eel trap and transport pilot project was initiated in 2008 as part of the Ontario Power Generation Action Plan for offsetting turbine mortality of American Eel at the Moses Saunders Generating Station (MSGS) (Greig et al. 2006; Ontario Power Generation Inc. 2012). Large eels, >800 mm, captured as by-catch from existing multi-species commercial fisheries in Lake Ontario and Lake St. Francis (an enlargement of the St. Lawrence River upstream of Montreal), were transported around the two generating stations (MSGS, Beauharnois) or released back into Lake St. Francis (upstream of Beauharnois Dam). Between 2008 and 2010, over 3,000 eels have been transferred downstream of the MSGS and Beauharnois generating facilities (DFO 2010b; Mathers and Pratt 2011).

Offsets – compensation

When mitigation options are insufficient or not possible, power companies have considered offsets or compensation for mortality of eels (Ontario Power Generation Inc. 2012). Between 2002 and 2007, 36 of 42 commercial hoop net fishing licences, targeting mostly yellow eels, were bought out from the Lac St-Pierre area and in 2009, 46 of 67 silver eel commercial fishery licences in the lower St. Lawrence estuary were bought out in a program funded by the Quebec Provincial government (75%) and Hydro-Quebec (25%). The net effect of these measures was a reduction in total catch (mortality) of yellow and silver eel phases of 53% in the Québec waters (DFO 2010b). No reduction in cumulative turbine mortality rates resulted from this action and exploitation rates in the silver eel fishery in the lower St. Lawrence River declined from values of about 22% in 1996-1997 to estimated values of 11% and 8% in 2010 and 2011, respectively (Chaput et al. 2014).

HABITAT ALTERATIONS

The Habitat Alteration threat considered is the incursion and deposition of sediments into water courses. The sources of sediments are broad and include urbanization (construction and removal of ground cover, surface hardening, loss of riparian zones), forestry (road construction, removal and destruction of ground cover, loss of riparian zones), mining (same as forestry), agriculture (removal of ground cover, tilling), bank erosion (loss of riparian areas exacerbated by waves from ships and boat traffic), dredging of waterways, and other land use or water activities where vegetative ground cover is removed or sediments are mobilized. The effects of this category of threats are most often expressed in terms of loss of habitat, lower growth rates, and lower survival due to density dependent effects of reduced or compromised habitat.

The silt and sediments threat can be managed by a number of operational statements which describe the conditions and the measures to be incorporated into a project in order to avoid negative impacts to fishes and fish habitat (Coker et al. 2010; DFO 2013). If the specific criteria and mitigation measures defined in the operational statement are applied to the activity covered by the operational statement, the activity can proceed and no harmful alteration, disruption or destruction of fish habitat is expected.

Additional mitigation measures are outlined in Coker et al. (2010) for activities that are not covered by an Operational Statement. The pathways of effects diagrams and the list of mitigation options that include silt and sedimentation as an outcome of an activity to avoid include: vegetation clearing (PoE 1), grading (PoE 2), excavation (PoE 3), use of industrial equipment (PoE 5), cleaning or maintenance of bridges or other structures (PoE 6), riparian planting (PoE 7), streamside livestock grazing (PoE 8), placement of material or structures in water (PoE 10), dredging (PoE 11), water extraction (PoE 12), organic debris management (PoE 13), addition or removal of aquatic vegetation (PoE 15), flow management (PoE 16), and structure removal (PoE 18) (Coker et al. 2010).

Sedimentation of rivers and estuaries is occurring throughout eastern Canada but the impact in terms of lost productivity of eel is not known and the benefits of mitigation measures to eel productivity have not been quantified (Table 7).

PARASITES AND DISEASES

Anguillicola crassus, the swim bladder parasite, is not endemic to American Eel but is now considered to be present in a large proportion of the American eel's distribution in eastern North America (Nilo et Fortin 2001). Infestations of the parasite in individual eels may lead to reduced foraging, lower energy reserves, and reduced swimming ability (Palstra et al. 2007), all factors which could potentially reduce the ability of infected adult eels to migrate and spawn successfully in the Sargasso Sea. The mitigation options to cope with this parasite depend upon the life cycle and the intermediate hosts which are required for the parasite to complete its life cycle. *A. crassus* is a nematode that establishes itself in the swim bladder of an anguillid eel via ingestion of an infected intermediate host including freshwater ostracods, various copepods or one of many paratenic fish species (see references in Aieta and Oliveira 2009). The parasite has been found in both freshwater and marine hosts, indicating that the parasite is not restricted to freshwater and can potentially be transferred to new locations through all salinity regimes and through many hosts. The vast array of potential hosts and the eel's generalist feeding behavior ensure that the parasite's distribution will not be limited by host availability (Aieta and Oliveira 2009). Because of limited home ranges of yellow eels, movements of eels may not enhance parasite spread between rivers, but transport of live eels and use of eels as live bait in the US may potentially spread the parasite (Aieta and Oliveira 2009). In addition, 6 of the 8 areas with the highest prevalence and greatest intensity of the parasite were in the vicinity of major shipping ports. It is suspected that the parasite may have been distributed via intermediate hosts found in ballast water. Ballast water has also been proposed as a vector for the introduction of the parasite in the Bras d'Or Lake area of Nova Scotia (Denny et al. 2013).

Mitigation options to control the spread of *A. crassus* must consider modes which can spread infected intermediate hosts and live infected eels (Table 8). Ballast water has been considered as a possible source of the oyster disease MSX which appeared in the Bras d'Or Lake of Cape Breton in 2002. As a result, restrictions prohibiting the transfer of live oysters for re-soaking, including spat, from the MSX positive area of the Bras d'Or Lakes to other locations in Canada were implemented (Stephenson and Petrie 2005). Current Ballast Water Control and Management regulations under the Canada Shipping Act (P.C. 2006-495 June 8, 2006) require ships traveling outside Canada's Economic Exclusion Zone (EEZ), whether coastal or transoceanic, to exchange their ballast water and to flush tanks that contain residual amounts of ballast water with saltwater before entering Canadian waters, although ships that operate exclusively in waters under Canadian jurisdiction are exempt from ballast water exchange regulations (DFO 2010a).

In the Atlantic Provinces, most fishers harvest eels using fyke nets or pots which they distribute in one or more bays, estuaries, or rivers. Fishers commonly assemble their catches in live-boxes while awaiting pick-up by the buyer. In most cases, eels are transferred only short distances (i.e. several km) between the point of capture and the holding site, but it's possible that some transfer distances are greater. This raises the possibility that transfer of eels from catch to holding sites could facilitate the spread of aquatic invasive species, including the swim bladder nematode *A. crassus*. Anthropogenic movements of aquatic organisms (other than lobster) are governed by the National Code on Introductions and Transfers of Aquatic Organisms. At present, Introductions and Transfers Committees do not oversee local transfers of eels by fishers. However, if it was deemed that such transfers pose a sufficient risk of transferring an undesirable species, these committees could begin to regulate such movements.

Eels, elvers as well as yellow and silver eels, are purchased live from fishermen, and transported live from fishing locations to holding facilities. The practice of exchanging water at onloading points may be a vector for parasite transfer. One way to address this is to structure sequential pickup of eels from non-infected areas to infected areas only.

Transfer and stocking of eels may be a vector for spreading the parasite (Pratt and Mathers 2011). In the Lake Ontario experimental stocking program, the glass eels destined for stocking were held in quarantine at one of three aquaculture facilities in New Brunswick or Nova Scotia and were only stocked once the health screening procedures were completed. Despite these measures, it has recently been reported that the swim bladder parasite *A. crassus* had been detected in eels sampled from Lake Ontario with the suspected source being the stocked eels (T. Pratt, DFO, pers. comm.). There are limits in fish health diagnostics to detecting pathogens and parasites which may be at very low prevalence and in which the infected animals do not show any overt clinical signs of infection.

ECOSYSTEM CHANGES

Ecosystem changes were assessed at a medium level of concern in Ontario, the southern Gulf of St. Lawrence and the Atlantic coast of Nova Scotia and the Bay of Fundy, primarily as a result of concerns with the spread and establishment of non-native species, primarily piscivorous fishes in the Maritime Provinces (Table 9). The establishment and spread of non-native piscivorous fishes in the Atlantic coast of Nova Scotia and Bay of Fundy also were of concern relative to the changes associated with prey and predator communities.

The non-native fish of concern in the Maritimes provinces are primarily Smallmouth Bass and Chain Pickerel, although Muskellunge has become established in the Saint John River (NB) (Bradford et al. 2004; DFO 2009a). Recently, Locke et al. (2011) developed a Rapid Response Framework to guide rapid response actions associated with introductions of non-native species. The framework is intended to facilitate the detection of suspected non-indigenous species and to prevent or manage their establishment in a new location. It is well known that there are very few effective tools for eradicating a non-indigenous species once established (Halfyard 2010).

All the recent introductions of non-indigenous Smallmouth Bass and Chain Pickerel in the Maritime Provinces have occurred as a result of unsanctioned stocking. Regulations that prohibit the possession of live fish in sport fisheries have been recently introduced in Nova Scotia as a means of reducing the opportunities for illegal introductions of non-native sport fish in that province. Reductions of non-native species abundances could be achieved by relaxing harvest regulations and/or prohibiting the return to the water alive of any non-indigenous species captured in commercial/recreational/aboriginal fisheries (Table 9).

In the southern Gulf of St. Lawrence, the changes in predator communities of concern were those associated with increased populations of fish-eating birds, primarily the cormorant (Chaput et al. 2014). One potential mitigation measure is predator control (Bowen and Lidgard 2011). Population control of cormorants was undertaken in Quebec between 1989 and 1994 (Bowen and Lidgard 2011) and has begun again in the Lac St. Pierre area of the St. Lawrence River. Similarly, control programs for cormorants were initiated in 2002 to 2005 in Lake Erie (Ontario) (Bowen and Lidgard 2011). In the US, control programs on cormorants have reduced the mortality rates and improved the recruitment rates of yellow perch (review in Bowen and Lidgard 2011). The effectiveness of predator control programs are difficult to predict, especially when the species targetted for protection make up a small fraction of the predator's diet. A review of avian piscivore diet studies in the Maritime Provinces indicated that eels comprised 3.5% of double-crested cormorant diets, 1.6% of great cormorant diets, 4.5% of common merganser diets, and 1.0% of belted kingfisher diets (Cairns 1998).

CLIMATE

Although not considered a threat, variations in oceanographic features associated with climate have been hypothesized to impact recruitment rates and abundance of American Eel in continental waters. One of the hypotheses of the causes of the reported declines in the abundance of the European Eel and the American Eel indices of the upper St. Lawrence River / Lake Ontario is the role of oceanographic variations that condition abundance of leptocephali and the recruitment of glass eels to the continent. Recent papers provide correlational evidence of ocean climate effects on eel recruitment, due to a combination of limited food (starvation of leptocephali) and variations in the strength and position of Gulf Stream (features that affect timing of metamorphosis and detrainment to the continent) (see Chaput et al. 2014 for synopsis of hypotheses). Ocean climate conditions, potentially interacting with lower spawner abundance, may have contributed to the low recruitment indices of juvenile eels into Lake Ontario, while maintaining an abundant supply of glass eels to the continental waters of the other portions of eastern North America.

A stocking experiment was undertaken in Ontario during 2006 to 2010 (Pratt and Mathers 2011; Pratt and Threader 2011; Ontario Power Generation Inc. 2012) with the goal of augmenting American Eel abundances in the productive rearing habitats where naturally recruiting eel abundances were low. The stocked glass eels originated from the Bay of Fundy region of New Brunswick and the Atlantic coast of Nova Scotia and totaled over 2 million glass eels / elvers stocked in 2008 and about 1.2 million stocked in 2009 (Pratt and Mathers 2011; Pratt and Threader 2011) with a combined total of almost 4 million animals between 2006 and 2010 (Ontario Power Generation Inc. 2012). Based on hypothetical guesses of survival in the first year (S = 0.05) and in subsequent years (S = 0.90), these stocking levels would correspond roughly to the equivalent of 30 thousand to 60 thousand juvenile eels (average age 5 years) recruiting to the Moses-Saunders eel ladder, values roughly 5% or less of the peak counts of the 1975 to 1986 time period. The contribution of these stocked eels to production of silver eels and subsequently to recruitment is not known (Table 10).

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TABLES

Table 1. Summary of threats assessed as medium or high concern for the five regions of eastern Canada (from Chaput et al. 2014).

Threat	Ontario	Quebec	Newfoundland and Labrador	Southern Gulf of St. Lawrence	Atlantic coast of Nova scotia and Bay of Fundy
Directed fishing for American Eel					
Commercial fisheries (large eels)	High[1]	Medium		Medium	Medium
Commercial fisheries (elver)					Medium
Physical Obstructions					
Loss of habitat	High	High	Medium	Medium	Medium
Fragmentation of habitat	Medium	Medium		Medium	Medium
Turbine mortality	High	Medium			Medium
Habitat alteration					
Silt and sediment			Medium	Medium	Medium
Parasites and diseases					
Swim bladder parasite				Medium	Medium
Ecosystem changes					
Changes in prey communities					Medium
Changes in predator communities				Medium	Medium
Non-native species invasions	Medium				Medium

[1] For Ontario, the commercial fishery for adult eel of concern is the one that occurs in the St. Lawrence River in Quebec

Table 2. Current management of directed commercial large eel fisheries by jurisdiction.

Jurisdiction	Fishing method	Gear allocations	Licences	Season	Fishing locations	Size restrictions	Timing of landings	Reporting measures
Newfoundland and Labrador	Pots, fyke nets	Licence holder can only use fyke nets or pots max 25 pots per licence in inland waters max 50 pots per licence in coastal waters max 5 fyke nets per licence holder (fishers who traditionally fished more than 5 fyke nets have been grandfathered in to fish max 2 nets per river system to max of 10 fyke nets (5 rivers)) max 15 fyke nets/fisher in coastal waters	165 licences	June 1 to Oct 31 for coastal pots July 1 to Oct 31 inland pots June 1 to Oct 31 for coastal fyke nets Aug 15 to Oct 15 inland fyke (limited by regulation); dates vary based on new moon	Licensed areas vary from single watershed, to multiple watersheds, and various proportions of coastal areas sites are restricted and specified on river systems, fishers are not permitted to move from their designated site site locations are noted in the licence conditions by latitude and longitude co-ordinates transfer of sites is not permitted on river systems unless the fish harvester meets stringent criteria.	Min. 20 cm	Eastern NL bulk of landing occur in Aug and Sept months	logbooks are required
Southern Gulf of St. Lawrence: Eastern New Brunswick	Fyke nets	As per conditions in Maritime Provinces Fishery Regulations Additional restrictions: • A maximum of one leader on any fishing gear of maximum leader length 31 metres. • Maximum of 2 wings of max. length 4 metres each. • Only single fyke nets are authorized except for a licence holder who can show that he has fished with gear other than a single fyke net in the past will be authorized to continue to do so as a	151 licences for total of 1,888 fyke nets	Consultations are conducted on a yearly basis to establish fishing seasons. In 2012 • Kent County : April 22 - June 30, Aug 15 - Oct 23 • Pokemouche River: April 22 - June 30, July 22 - Sept 30 • Tabusintac River: Aug 1 to Oct 14 • All other	Licensed areas vary from single watershed, to multiple watersheds, and various proportions of coastal areas.	Min. 53 cm		47 active licences in 2011

Jurisdiction	Fishing method	Gear allocations	Licences	Season	Fishing locations	Size restrictions	Timing of landings	Reporting measures
		grandfather clause which terminate when the licence is reissued.		watersheds: May 1 - June 30, Aug 1 - Oct 18				
	Longline	3,500 hooks over all licences	7					
Southern Gulf of St. Lawrence: Nova Scotia	Fyke nets, pots		144	Sept 1 - Oct 24	Specific site restrictions.	Min. 53 cm	Fall	Logbook required.
	Spears			Jan 15 - April 30	Tidal waters of NS that border of the Gulf of St. Lawrence and the Northumberland Strait subject to closures in portions of Pomquet Harbour and East River of Pictou. Maximum 3,400 lumens (flambeau fishing)		Winter	Logbook required.
Southern Gulf of St. Lawrence: Prince Edward Island	Fyke nets. Commercial spearing was closed in 2005. closed in 200?	Fyke nets must be at least 200 m apart.	121 trap net and spear, 114 are trap net only 1 is eel pot and spear	Aug. 23 – Oct. 23	Tidal waters	Min. 53 cm	Aug. to Oct.	Voluntary logbook
Atlantic Coast of Nova Scotia and Bay of Fundy	Longline, setlines, traps, pots, dipnet	Approximately 27,000 units of commercial gear Some maximum leader lengths for eel traps distance of 200 m must be maintained from any fishing gear previously set Fishing gear cannot be left unattended for more than 72 hours from sunrise to sunset eel traps must have a 90 cm opening to allow fish to escape and fyke nets must be rendered incapable of	359 licences; limited entry (no additional licences) commercial licence is only permitted to a fisherman registered in the preceding year and who actively engaged in fishing for some species in the preceding year	March – December Closed season for eel traps in inland waters from Nov. 1 to Aug 14	Virtually all inland and tidal waters	Min. 35 cm	Eel catches are more regulated by water temperature than by official seasons and most landings occur between May and November	mandatory logbook provides data on daily effort and catch;

Jurisdiction	Fishing method	Gear allocations	Licences	Season	Fishing locations	Size restrictions	Timing of landings	Reporting measures
		catching fish; there is one formal Advisory Committee for Southwest New Brunswick and ad-hoc meetings in the rest of the Region as may be required	licence holder is not required to fish annually to retain the licence					
Quebec: St. Lawrence Estuary	Tidal weir	52 weirs with total of 8,721 m of leader	21	1 August to 15 November	Tidal waters in St. Lawrence estuary, along shore	None	Fall	
Quebec: Lac St. Pierre	Hoop net		6					
Quebec: Lac St. François and Ottawa River	No information available							
Ontario	Commercial fishery closed in 2004							

Table 3. Mitigation options for commercial large eel fisheries.

Potential measures / alternatives	Potential to contribute to recovery	Contribution to recovery potential quantifiable?
Reductions in effort		
Reduce number of licences	Latent effort present in the fisheries so retirement of licences may not result in reduced exploitation rates and reduced mortality on eels unless very large reductions are put in place. For example: in the eastern New Brunswick fishery in 2011, a total of 115 t were reported by 47 licence holders, out of a total of 151 licences.	Assessment of effectiveness requires indicators of active licence holders. Harvest data in most areas of the Maritimes Region are incomplete. The introduction of mandatory logbooks in DFO Newfoundland and DFO Maritimes regions should improve harvest data collection and assessments. In DFO Gulf Region, PEI, logbooks are voluntary.
Reduce number of gear units per licence	Latent effort present in the fisheries so reduction of gear units per licence may not result in reduced exploitation rates and reduced mortality on eels unless very large reductions are put in place and/or accompanied by licence reductions.	
Change gear dimensions	Changes in dimensions of trap gears may reduce the efficiency of individual units. If there are latent gear in the fisheries, changes in gear dimensions may be offset by additional gears being fished and may not result in desired reductions in exploitation rates and reduced mortality on eels.	
Shorten fishery season	Effort and landings are generally not distributed evenly through the season. Reduction in fishing season has the potential to reduce harvests and exploitation rates or it may displace effort which would have been deployed from an active period to a previously less active time of year	
Change minimum spacing of gear	Increases in minimum gear spacing are likely to reduce harvest levels in areas where gear is currently set at high densities. Effectiveness may be enhanced by the restricted home ranges of yellow eels such that a reduction of nets in a watercourse will likely reduce the encounter rate between eels and gear, and therefore reduce In high density situations, could result in a decrease in the number of nets per watercourse but increased numbers of watercourses being	There is limited data on the practice of spacing of gears and no experimental data are available to test the supposition that a reduction of the number of nets in a watercourse will reduce harvest levels
Restrict individual gear placements	Under a berth system, a fisher could delay setting nets without fear of losing the fishing site to another. If there is a reduction in active effort, it could result in reduced exploitation	The extent to which eel fishing effort is artificially increased by the placement of nets to hold sites is not clear.

Potential measures / alternatives	Potential to contribute to recovery	Contribution to recovery potential quantifiable?
Restrict size harvested		
Minimum size limit	Reduces lifetime exploitation on yellow eels by exposing animals to fewer years in the fishery. Shifts exploitation pressure to silver eels or larger size yellow eels. Result in reduced cumulative mortality on eel but will have no effect on exploitation rate of larger eel unless accompanied by limitations on effort (gears, seasons).	Requires length frequency data from the fishery to assess options and expected results.
Maximum size limit	If maximum size limit is below the mean size at maturity, this measure could reduce harvests on larger silver eels Shift exploitation pressure on yellow eel Result in reduced mortality on large eels once they pass the maximum size. No effect on exploitation rate of smaller eels unless accompanied by limitations on effort (gears, seasons).	
Size slot	Combination of min and max size limit, reduces exploitation on small eels and large eels but could increase overall exploitation of eels in the slot if effort is increased to maintain harvest levels.	
Harvest limits (including purchase of eels for stocking or release)	Used to manage absolute eel mortality Catch limits may result in higher exploitation if abundance declines and fishery increases effort to maintain catches	Assessment of effectiveness requires indicators of active licence holders. Harvest data in most areas of the Maritimes Region are incomplete. The introduction of mandatory logbooks in DFO Newfoundland and DFO Maritimes regions should improve harvest data collection and assessments. In DFO Gulf Region, PEI, logbooks are voluntary. In Quebec, ? Require indicators of absolute or relative abundance to assess exploitation rates.

Table 4. Current management of the directed commercial glass eel and elver fisheries by jurisdiction.

Jurisdiction	Fishing method	Gear allocations	Licences	Season	Fishing locations	Size restrictions	Timing of landings	Reporting measures
Newfoundland			1 licence holder					logbooks are required
Southern Gulf of St. Lawrence	No fishery							
Atlantic Coast of Nova Scotia and Bay of Fundy	Dipnets, nets, pots	licences holders have assigned rivers and quotas; elver traps must be screened to prevent other species from entering the gear	9		Permitted on rivers that did not have established commercial fisheries for large eels at the time the authorizations were granted. Distributed among 82 named rivers/streams	less than 10 cm (4”) in length;		daily hail-in and hail-out requirements; daily landing reports by dockside monitoring; 100% mandatory weigh-outs for all elver shipments
Quebec	No fishery							
Ontario	No fishery							

Table 5. Mitigation options for commercial elver fisheries.

Potential measures / alternatives	Potential to contribute to recovery	Contribution to recovery potential quantifiable?
Reductions in effort		
Reduce number of licences	Not expected to have much latent effort in this fishery Effective if reduction in licences accompanied by contraction of areas fished and no increase in quota per licence.	Catch and effort data of excellent quality in DFO Maritimes Regions. Catch and effort data are not available for Newfoundland and Labrador Region. Consequence of elver fisheries to future silver eel abundance is not understood.
Reduce number of gear units per licence	Fishery is managed by individual quota. Most fishing is by dipnet. If individual quotas are not changed, changes in number of fixed gear untits (pot, net) per licence are not expected to reduce absolute numbers of elvers harvested unless changes are made to other components (season for example)	
Change gear dimensions	Fishery is managed by individual quota. If individual quotas are not changed, changes in dimensions of trap gears are not expected to reduce absolute numbers of elvers harvested.	
Shorten fishery season	Effort and landings are generally not distributed evenly through the season. If individual quotas are not changed, reduction in fishing season will not reduce mortality, additional effort may be placed in season to harvest the quota.	
Restrict size harvested		
Minimum size limit	Not an option for this fishery due to definition of glass eel / elver	
Maximum size limit	Maximum size limit defined by condition of licence (regulation?)	
Harvest limits (including purchase of eels for stocking or release)	Used to manage absolute eel mortality Catch limits may result in higher exploitation if abundance declines and fishery increases effort to maintain catches	Assessment of effectiveness requires indicators of active licence holders. Harvest data are very good for these fisheries in Maritimes Region. Consequence of elver fisheries to future silver eel abundance is not understood Require indicators of absolute or relative abundance to assess exploitation rates.

Potential measures / alternatives	Potential to contribute to recovery	Contribution to recovery potential quantifiable?
Rotational fisheries using annual area closures	Rotational fishing would permit periodic pulses of elvers to recruit to rivers unimpeded by fishing, thus replenishing the standing stock of eels to individual rivers. Harvests would be satisfied from a smaller number of fishing locations potentially increasing the annual exploitation rates in the rivers which are fished.	Assessment of effectiveness requires indicators of abundance of standing stock of eels in fished and unfished rivers. Consequence of elver fisheries to future silver eel abundance is not understood.

Table 6. Mitigation options for physical obstructions.

Potential measures / alternatives	Potential to contribute to recovery	Contribution to recovery potential quantifiable?
Loss of habitat		
Removal of barrier Pathways of effects described (PoE 18) and mitigation measures identified from Coker et al. (2010)	Best solution for upstream and downstream passage issues. Provides natural seasonal and annual migrations of life stages of eels. In some situations, the removal of a barrier and loss of a headpond may result in reduced production of eels as production is higher in lacustrine systems compared to fluvial system.	Can be quantified with before and after monitoring programs
Upstream and downstream fish passage (see Solomon and Beach 2004; OWA 2010) Pathways of effects described (PoE 16, 17) and mitigation measures identified from Coker et al. (2010)	Facilitate seasonal and annual migrations of life stages of eels. Not as effective as removal of barriers but lacustrine habitat can be maintained.	Can be quantified with before and aftermonitoring programs
Habitat fragmentation		
Guidelines have been developed for new installations, refurbishments (New Brunswick 2010; Gosse et al. 1998) Pathways of effects (PoE 10, 16, 17) and mitigation measures identified from Coker et al. (2010)	Eels utilize a range of habitats (Pratt et al. 2014). In some areas, eels migrate seasonally or annually between freshwater and brackish water. Some American Eel may make seasonal migrations in spring and fall within freshwater areas. The role of these habitat shifts in eel survival and production has not been directly measured but they should be assumed essential for species fitness.	Can be quantified with before and after monitoring programs
Mortality in turbines at Hydro dams during downstream migration		
Turbine design	Difficult to retrofit existing facilities Considerations for new facilities	Possible. Studies to assess turbine mortality rates are required. Many factors can affect estimates of mortality rates.
Water management	Extent that water management strategies can contribute to recovery depends upon the proportion of migrating eels which can be directed away from turbine intake and into alternate downstream passage routes. These are very likely to be site specific.	Possible Studies to assess passage success are required. Many factors can affect estimates of mortality rates.
Barriers (physical, behavioural, bypasses)	Seems possible to deflect a high proportion of eels away from turbines. Size of the facility is a critical factor in the applicability. Screens are not recommended for large facilities where debris loading may exceed the limits of the cleaning devices.	Possible Studies to assess proportion of eels diverted are required. Many factors can affect efficiencies, likely site specific.

Potential measures / alternatives	Potential to contribute to recovery	Contribution to recovery potential quantifiable?
Trap and transport	Possible to capture eels and transport them around facilities. Proportion of eels transferred depends on capture effort which may need to be substantial in large areas where individual gear catchabilities may be low. The higher the mortality rate associated with the turbines, the greater the contribution of trap and transport to increasing eel escapement around hyrdodams.	Quantifiable as number of animals trapped and transported would be known.
Offset – compensation (buyback of fishing licences)	Reduction of a significant portion of active licences may contribute to increased escapement of silver eels. Most effective if the fishery occurs after all turbine mortality. In the lower St. Lawrence River, buyback of licences resulted in a reduction in total catch (mortality) of yellow and silver eel phases of 53%. No reduction in cumulative turbine mortality rates resulted from this action. Exploitation rates in the silver eel fishery in the lower St. Lawrence River declined from about 22%% in 1996-1997 to estimated values of 11% and 8% in 2010 and 2011, respectively. At some point, will run out of fishing licences to retire.	Possible to quantify reductions in fishery exploitation rates resulting from buy-back programs.

Table 7. Mitigation options for habitat alteration.

Potential measures / alternatives	Potential to contribute to recovery	Contribution to recovery potential quantifiable?
Silt and sediments		
Operational statements have been developed for a number of routine activities. Pathways of effects and mitigation options described for a number of other activities (PoE 1, 2, 3, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, and 18) (Coker et al. 2010)	Not known the extent to which silt and sedimentation have contributed to reduced eel production	Not currently possible

Table 8. Mitigation options for parasites and diseases.

Potential measures / alternatives	Potential to contribute to recovery	Contribution to recovery potential quantifiable?
Swim bladder parasite		
Regulation of ballast water exchange for inter- and intra-continental traffic	Control on further spread and prevalence of parasite in eel may slow further erosion of reproductive fitness of eel	Can monitor effectiveness of measures in controlling further range expansion of parasite. Difficult to quantify effects on silver eel migration success and reproduction
Regulation of transport of live eel among jurisdictions - Transport and water exchange from infected to non-infected areas only		
Regulation of stocking of eels across jurisdictions		

Table 9. Mitigation options for ecosystem changes.

Potential measures / alternatives	Potential to contribute to recovery	Contribution to recovery potential quantifiable?
Non-native species		
Prohibition on possession of live fish in sport fisheries	Reduce the potential spread of non-native fish which can compete for food or directly prey on eel Contribution to recovery not known.	Not currently possible to assess.
Relaxing harvest regulations (bag/size/season limits) on non-native fish and prohibiting the release of non-native fish bycatch in commercial/recreational/aboriginal fisheries.	Reduce the abundance of non-native fish which have become established.	

Table 10. Mitigation options for climate.

Potential measures / alternatives	Potential to contribute to recovery	Contribution to recovery potential quantifiable?
Conservation stocking: Augment eel abundance in productive rearing habitats where naturally recruiting eel abundances are low.	Young stages are taken from areas where there is high mortality due to limits on carrying capacity. The contribution of these stocked eels to production of silver eels can be assessed.	Production of silver eels from stocking program can be quantified. Contribution of stocking program to recruitment of next generation cannot be quantified.