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Recovery Potential Assessment for the American Eel (*Anguilla rostrata*) for eastern Canada : description and quantification of threats

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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 the identification and assessment of threats to American Eel for eastern Canada. The first section describes the general threat categories with a focus on relating the activities, factors and the stress which can act on American Eel mortality or productivity. Where possible, the causal mechanism linking the stress factor and the population vital rate are described. This serves as the basis for describing the causal certainty that links a threat and its associated activities to the population dynamics of the American Eel. The second section of the document describes how the level of concern of the threats is qualified, by determining the magnitude (severity), extent (spatial), frequency (temporal) and causal certainty of each threat to American Eel. In the third section, the level of concern of threats is assessed for five jurisdictions in eastern Canada (province of Ontario, province of Quebec, Newfoundland and Labrador, southern Gulf of St. Lawrence, Atlantic coast of Nova Scotia/ Bay of Fundy). Common threats which score as medium or high level of concern across the regions include directed commercial fisheries for American Eel, and physical obstructions. Region specific threats, not shared across all regions, include turbine mortality (within physical obstruction category), habitat alterations, introduction of the swim bladder parasite, and changes in ecosystems mostly associated with non-native species introductions and spread. Climate factors primarily acting in the ocean environment are considered to be important in determining the abundance of American Eel and are treated as a limitation to population recovery rather than a threat.

Évaluation du potentiel de rétablissement de l'anguille d'Amérique (*Anguilla rostrata*) dans l'est du Canada : caractérisation et quantification des menaces

RESUME

Ce document porte sur les composantes du cadre de référence pour l'évaluation du potentiel de rétablissement liées à la caractérisation et à la quantification des menaces à l'anguille d'Amérique de l'est du Canada. La première section du document présente une description générale par catégorie de menace et met l'emphase sur les liens entre les activités et les facteurs de stress qui modifient la mortalité et la productivité de l'anguille d'Amérique. Dans la mesure du possible, le mécanisme en cause et effet reliant les facteurs de stress au taux vital de la population est décrit. Cette évidence sert à évaluer le niveau de certitude du cause et effet reliant les menaces et les activités associées aux dynamiques de population de l'anguille d'Amérique. La deuxième partie du document décrit l'approche qui a servi à évaluer le niveau de préoccupation de ces menaces. L'évaluation tient en considération quatre facteurs dont la sévérité, l'étendu spatial, la fréquence temporelle, et la certitude du cause et effet de la menace sur l'anguille d'Amérique. Enfin, dans la dernière section, les niveaux de préoccupation des menaces sont évalués pour chacune des cinq régions de l'est du Canada comprenant les provinces de l'Ontario et du Québec, et les régions administratives de Terre-Neuve-et-de-Labrador, du sud du golfe du Saint-Laurent, et l'ensemble de la côte atlantique de la Nouvelle-Écosse et de la baie de Fundy. Les menaces de niveau de préoccupation moyen et élevé communes à travers les régions sont les pêcheries commerciales sur les grandes anguilles et les obstructions physiques au passage. Les menaces spécifiques à certaines mais pas toutes les régions incluent la mortalité attribuée au passage dans les turbines (dans la catégorie générale de menace associée aux obstructions physiques), les altérations d'habitat, l'introduction et la propagation du parasite de la vessie natatoire, et les changements dans les écosystèmes associés à l'introduction et la propagation des espèces non-indigènes. Les facteurs climatiques principalement dans le milieu océanique sont jugés avoir un rôle important dans la détermination de l'abondance de l'anguille d'Amérique mais ces facteurs représentent une contrainte plutôt qu'une menace au rétablissement de l'espèce.

1. INTRODUCTION

The Terms of Reference (TORs) for the Recovery Potential Assessment include an identification of threats to the species which can limit its recovery or persistence. The definition of "threat" in Environment Canada (2007) is the basis for the analyses presented in this document.

> "A threat is any activity or process (both natural and anthropogenic) that has caused, is causing, or may cause harm, death, or behavioural changes to a species at risk, or the destruction, degradation, and/or impairment of its habitat, to the extent that population-level effects occur. In essence, it is any activity or process that imposes a *stress* on a species at risk population which contributes to, or perpetuates, its decline or limits its recovery. A threat is the stimulus creating the stress response. A threat could be a human activity (*e.g.*, shooting, pollution, residential development), a human-induced change in a natural process or species dynamic (*e.g.*, altered fire regime, introduced species, reduction in prey populations), or a natural process or disaster (*e.g.*, erosion, browsing, hurricane). Naturally limiting factors such as aging, disease, and predation are not normally considered threats unless they are altered by human activity or pose a threat to a critically small or isolated population." (Environment Canada 2007, p. 2).

DFO (2010a) confirmed this definition for threat in the science processes associated with the assessment of a species status, and its recovery potential assessment. As indicated in Environment Canada (2007) and reiterated in DFO (2010a), it is important to make the distinction between general threats (e.g. agriculture) and specific threats (e.g. siltation from tile drains). Environment Canada (2007), proposed a hierarchical system for naming and grouping related threats from broad threat categories to specific details. Specifically, threats were categorized from broad category (such as Habitat Degradation), through a general threat description (such as Removal of riparian vegetation through over-grazing), followed by the specific factor or stimulus causing stress (such as river siltation), to finally a description of the stress as indicated by specifying which demographic attribute of a population, or a physiological or behavioural attribute of an individual is potentially impaired by the threat.

The numerous recovery potential assessments published by DFO in recent years have not always followed the hierarchical structure for describing and quantifying threats to species as outlined by Environment Canada (2007). Variants of the broad threat categories have been used as a means of facilitating the identification and assessment of threats specific to the species under consideration.

In the context of this evaluation, a threat is considered to be any anthropogenic or natural factor which increases mortality or reduces productivity of the species outside the range of values which allowed the species to persist and prosper within the natural (pre-human) state of its environment. The anthropogenic factor(s) could affect the species along numerous pathways including but not exclusively: as direct and immediate mortality of individual animals at different stages of its life cycle, through physical injury of individuals resulting in increased vulnerability to mortality from secondary factors (pathogens, predation, starvation), by reducing or constraining access to energy and resources resulting in increased mortality or reduced productivity (lower fecundity, reduced energy reserves for migration), and via behavioural disturbance which can affect the ability of individual animals to access features of habitat required for feeding, sheltering, growth and survival.

In this document, the approach used is similar to those used in Recovery Potential Assessments of large bodied species historically subjected to commercial / recreational / aboriginal fisheries such as Lake Sturgeon (DFO 2010c) and Atlantic Salmon (DFO 2013).

The threat categories used are most similar to those utilized in the Atlantic Salmon assessment (DFO 2013) and are a hybrid of activity and threat which were considered most readily interpretable by the science and management evaluators; for example using the general threat category “directed fisheries” rather than the threat category “biological resource use” as presented in Environment Canada (2007) or “Mortality, injury or reduced survival” as used in DFO (2010c) for lake sturgeon.

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

- TOR 9. Identify the activities most likely to threaten the habitat properties that give the sites their value, and provide information on the extent and consequences of these activities.
- TOR 11. Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.
- TOR 16. Provide advice on the extent to which various threats can alter the quality and/or quantity of habitat that is available.
- TOR 18. Quantify to the extent possible the magnitude of each major potential source of mortality identified in the pre-COSEWIC assessment, the COSEWIC Status Report, information from DFO sectors, and other sources.
- TOR 20. Assess to the extent possible the magnitude by which current threats to habitats have reduced habitat quantity and quality.

The document is organized in three parts. First, the general threat categories are described (Section 2). In this section, information is provided on the activities, factors and the stress which can act on American Eel mortality or productivity. Where possible, the causal mechanism linking the stress factor and the population vital rate are described. This narrative section of the document serves as the basis for describing the causal certainty that links a threat and its associated activities to the population dynamics of the American Eel. The next section (3) of the document describes how the level of concern of the threats is qualified, by determining the magnitude (severity), extent (spatial), frequency (temporal) and causal certainty of each threat to American Eel. The final section (4) quantifies and assesses the threats specific to five jurisdictions in eastern Canada (province of Ontario, province of Quebec, Newfoundland and Labrador, southern Gulf of St. Lawrence, Atlantic coast of Nova Scotia/ Bay of Fundy.

2. THREATS AND LIMITING FACTORS

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (2012) identified the following threats to American Eel of eastern Canada:

> “In fresh water, barriers erected in watercourses severely impede upstream migration of juvenile eels if no fish passage is provided. Impeded access to the Ottawa River, Lake Ontario, and Lake Champlain resulted in substantial cumulative loss in access by eels to formerly productive rearing habitat, e.g., at least 12,140 km² of eel freshwater habitat (10 m or less in depth) in the St. Lawrence River watershed. The turbines of hydroelectric dams also impose substantial mortalities (up to 40%) during passage through multiple dams as maturing fish migrate downstream toward the spawning grounds. Vulnerability to fisheries and bioaccumulation of contaminants are also important threats.

> An exotic swim bladder nematode parasite may be negatively affecting eels. The parasite has been found in Nova Scotia (Cape Breton Island), New Brunswick, and Lake Ontario. Climate change and shifting oceanographic conditions and supplementation of eels by stocking of wild-recruits (now suspended) may also pose risks."

The following section provides details on potential threats to American Eel and provides a basis for determining the causal certainty of potential impacts of the threats on American Eel population dynamics in terms of survival, growth, migration success, and reproductive success.

2.1. FISHERIES

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 (Table 2.1.1).

As a result of the semelparous nature of American Eel, all fisheries take place on immature individuals that have not spawned. Management objectives identified in the Canadian Eel Management Plan were to reduce mortality rates by 50% from a base period (DFO 2010d). There are very few exploitation rate estimates for fisheries in eastern Canada. Estimates of the proportion of the fisheries landings to the yellow eel standing stock biomass in the southern Gulf of St. Lawrence were in the range of 7% to 8% for 1997 to 2008 (D. Cairns, DFO, pers. comm.). The exploitation rates of silver eels migrating from Lake Ontario and the upper St. Lawrence River in the fishery in the lower St. Lawrence River were estimated at 25% in 1996 and 20% in 1997 (Caron et al. 2000). More recently following on an important reduction in the fishing effort, it was estimated at 11% (COSEWIC 2012). Annual exploitation rates in elver dipnet fisheries in a small river in the Atlantic coast of Nova Scotia were estimated to have ranged from 30.8% to 51.8% over three years of assessment (Jessop 2003).

Reference points in terms of biomass or fishing mortality rates have not been established for any eel fisheries in eastern Canada (DFO 2010d). Chaput and Cairns (2011) used Spawner per Recruit analysis to calculate reference points for 30%SPR and 50%SPR for American Eel based on assumed life history characteristics. For eels with biological characteristics of the southern Gulf of St. Lawrence, if fishing occurred only at the silver eel life stage or at the elver life stage, the removal rate corresponding to a loss of 50%SPR was 50% (F = 0.69). In contrast, using identical life history characteristics, the annual removal rate for 50% SPR for a fishery on the yellow eel stage and for which individual animals are exposed to the fishery over multiple years was 11% (F = 0.12) (see Section 2.13). There were other consequences to fishing yellow eels versus silver eels; in the yellow eel fishery, silver eel age is shifted to younger animals which are generally smaller and contributes to a further loss of spawner biomass potential.

2.1.1. Direct and delayed mortality

The American Eel has been fished historically in all regions of eastern Canada in aboriginal, commercial and recreational fisheries (Eales 1968; Peterson 1997; DFO 2010c). Life stages harvested include elvers on their migration to rivers, yellow eels as residents, and migrating silver eels. Various gears are or have been used to fish eel. The majority of gears are variations of traps or pots which capture and hold the fish alive until the gears are fished; this allows for the selective release of animals back to the water if desired. 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 used in the eel fisheries in Lake Ontario and there was one licence that permitted electrofishing (Stewart et al. 1997). Peak reported landings from commercial fisheries of yellow and silver American Eel for Canada, as recreational and aboriginal fisheries catches are rarely if ever reported in these statistics, were 1,215 t in 1971 (Figure 2.1.1).

One common gear still used in the recreational fisheries of the three Maritime provinces and on the west coast of Newfoundland, mostly in the Bay St. Georges area, is spearing where a harpoon is used to jab and retrieve the fish (Eales 1968; Paulin 1997). Eels which are accidentally not retained by the gear may suffer injury as a result of jabbing, the extent of these injuries on eels where this fishing practice takes place has not been documented. 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 the southern Gulf of St. Lawrence fisheries for mandatory retention of all eels in the recreational spear fishery 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 2010c).

Fisheries on elver life stages occur in some rivers of the Bay of Fundy (Jessop 1998) and recently a fishery began in Newfoundland. Elvers are captured and marketed alive. Reported landings of elvers ranged from 100 to 4,100 kg between 1990 and 2007 (Bradford 2013; Cairns et al. 2014); one kg of elvers represents approximately 5,500 individual animals (Jessop 2003).

The assessment by Cairns et al. (2012b) provides an indication of the proportion of the coastal and estuary area of eastern Canada that would be potentially exposed to eel fishing gear. Overall in eastern Canada, the proportion of areas exposed to fishing gear is just over 6%, with the fisheries footprint most important in eastern Gulf New Brunswick and Prince Edward Island. There are no eel fisheries reported in large areas of the east coast of Canada including the north shore of the Gulf of St. Lawrence, Anticosti Island, the Gaspé Peninsula including most of the Bay of Chaleur coastline, and in large stretches of the northeast, south, and west coasts of Newfoundland (Cairns et al. 2012b).

The extent of illegal fisheries for eel is unknown. Yellow and silver eels are not known to be extensively illegally fished however ICES (2001) indicated that:

> “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 discrepancies 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.” (ICES 2001, p. 3).

The elver fishery has a very high economic value and there are concerns in some jurisdictions (State of Maine) of unsanctioned (illegal) fisheries occurring.

Eels are captured in generally low quantities in some freshwater trap fisheries of Ontario and Quebec, and in estuarine fisheries for diadromous fish in the Maritime provinces, particularly the gaspereau fisheries. Retention of bycatch eels is prohibited and the animals must be returned to water immediately with the exception of cases where special authority to possess the fish for research is granted.

2.1.2. Life history and demographic consequences of fisheries

Fishing mortality imposed on the stock will change the equilibrium point of the population. With the exception of the dynamics in overcompensatory models (Ricker type), the equilibrium point of spawners and recruitment will be lower when mortality increases. However, the losses of individual eels in fisheries may be offset by improved growth and survival of the remaining individuals resulting from reduced competition for limited resources (density dependent effects). There is evidence in literature of higher survival rates and increased growth rates at lower densities (De Leo and Gatto 1996; Bevacqua et al. 2011). The upstream migration of eels into freshwater has been hypothesized to be stimulated by high densities (McCleave 2001) and therefore fisheries exploitation which reduces densities may reduce the upstream migration of eels. Additionally, variations in densities may in some cases modify the sex ratio, with more males being produced at higher densities (Acou et al. 2011).

Table 2.1.1. Summary of fisheries threats and associated stress.

General threat	Specific threat	Stress	Causal certainty
Directed fisheries (aboriginal, commercial, recreational)	Fishing with fyke nets, traps, pots and other live capture gears, spearing, longlines and set lines	Direct mortality of retained individuals leading to reduced spawner abundance	Known to occur - reported landings from fisheries. Extensive footprint of fishing gears in eastern Canada in the southern areas. No defined reference points to assess the level of fishing mortalities which are sustainable for the species and which does not lead to population level declines
	a) Fishing with fyke nets, traps, pots and other live capture gears b) Spearing	Delayed mortality of released individuals due to injury	a) Not known but best management practices would allow for good post-release survival from live capture gears b) Not quantified but expected and of sufficient concern that management prohibits release of speared individuals which are captured.
	Fishing with fyke nets, traps, pots and other live capture gears, spearing, longlines and set lines	Changes in heritable population demographics associated with size/stage selective fishing leading to changes in spawner abundance and fitness	Heritability of phenotype is not known. Minimum size limits in yellow eel fisheries expose fast growing individuals to the fishery first but overall exploitation may be higher on slower growing individuals because they may spend more time between the size recruiting to the fishery and the size at maturation and migration out of the fishery. Fisheries that occur in estuaries select against that life history strategy. Eels rearing in freshwater for the most part escape these fisheries.
	Fishing with fyke nets, traps, pots and other live capture gears, spearing, longlines and set lines	Compensatory response of population vital rates associated with reduced density of eels in fished areas leading to improved or reduced spawner abundance	Responses could include: changes in mortality rates, growth rates, variations in extent of migrations to upstream habitats. Known and reported in European Eel studies and known from aquaculture operations (reduced growth and increased mortality as densities increase) Hypothesized: upstream migration of eels favoured by high densities.
Illegal fisheries	Fishing with any gear type	Direct mortality of retained individuals leading to reduced spawner abundance	Known to occur With exception of the elver fisheries which is of high economic value, interest in illegal fisheries is not expected to be important.
Bycatch in other fisheries	Fishing with traps, pots, trawls, angling.	Direct mortality of retained individuals leading to reduced spawner abundance	Bycatch known to occur in estuary and freshwater trap fisheries. Few records of bycatch of eels in marine fisheries. General prohibition on retaining bycatch of eels in most fisheries.
		Delayed mortality of released individuals from injury leading to reduced spawner abundance	Not known but best management practices would allow for good post-release survival from live capture gears.

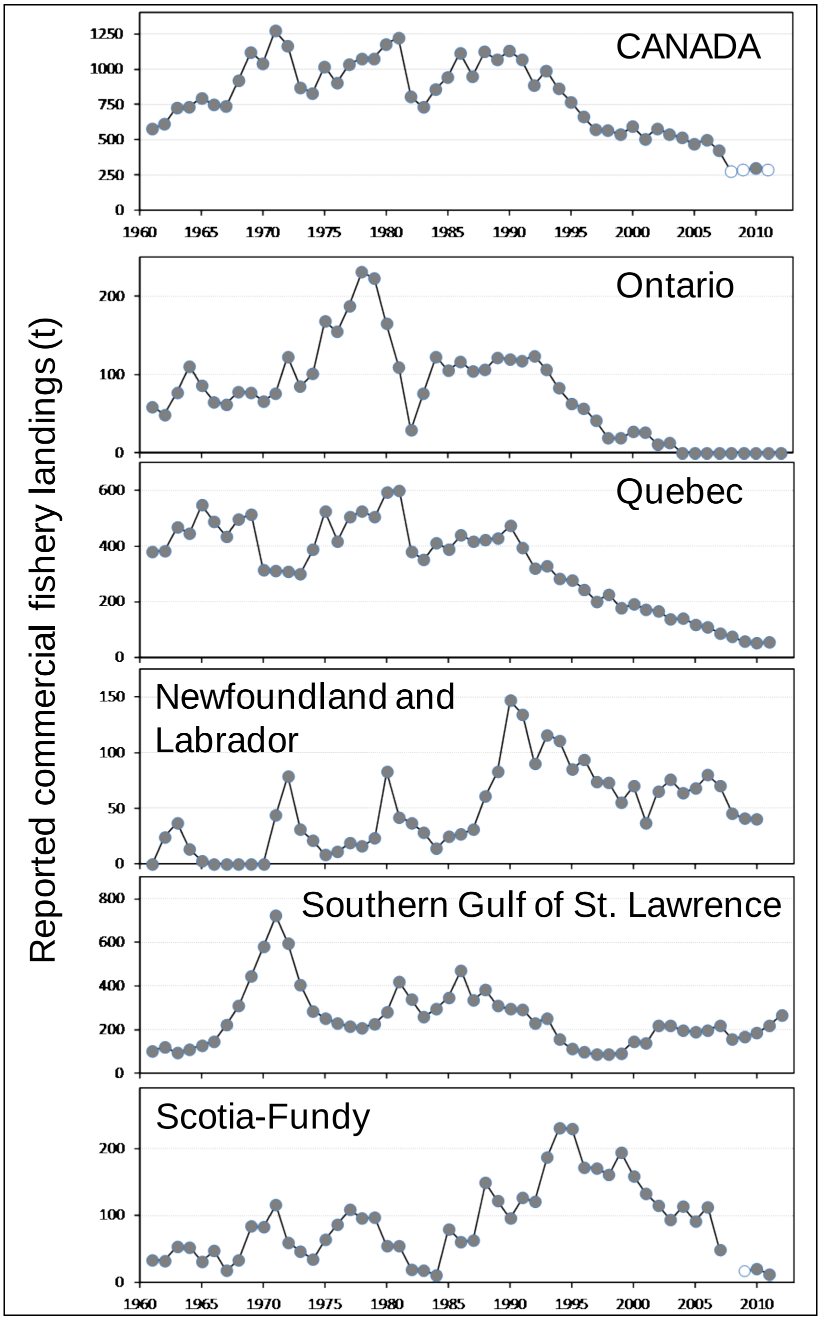

Figure 2.1.1. Reported landings (t) of yellow and silver eel from the commercial fisheries of Canada (top panel) and by jurisdiction (Ontario, Quebec, Newfoundland and Labrador, southern Gulf of St. Lawrence, Atlantic coast of Nova Scotia and Bay of Fundy) for 1961 to 2011. Data are extracted from Table 36 of Cairns et al. (2008) with updates from Cairns et al. (2014). Note that the Ontario fishery was closed in 2004. The symbols in white represent years when only partial information is available.

2.2. PHYSICAL OBSTRUCTIONS

The Physical Obstructions threat category encompasses the broad class of 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 (Table 2.2.1). The obstruction of movements of fish can take many forms (barriers with or without upstream and downstream passage), occur at many scales (large dams to culverts at road crossings), and the resulting stress to the individual and population manifests itself in numerous ways. The considered responses of eels to these stresses include:

- Lower growth rates and lower survival due to habitat fragmentation that interferes with seasonal and life cycle migrations between the saline and freshwater habitats, between fluvial and lacustrine habitats.
- Lower total production of animals due to single and cumulative obstructed access to upstream rearing areas (density dependent effects on growth rates, survival, and condition of eels blocked below barriers).
- Lower survival and lower growth rates associated with delays in migration and slower rate of migration (predators targeting aggregations of eels accumulating below barriers), increased energy expenditures to find access points (eel ladders or spillways), increased metabolic costs of ascending difficult structures or delayed migration (energy expenditures of excessive swimming).
- Delayed mortality resulting from injuries of animals moving over barriers.
- Direct mortality and delayed mortality due to injuries of animals passing through turbines.
- Changes in growth rates and survival due to changes in life history parameters (growth rate, survival) associated with changes in aquatic communities in impoundment situations versus fluvial areas. In some cases, the lacustrine habitat of impoundments may improve growth and survival resulting in increased yield of silver eels relative to that produced in the pre-flooded fluvial habitat.

2.2.1. Loss of habitat

Pratt et al. (2014) summarize the extent of habitat which has become inaccessible to American Eel in eastern North America. In the eastern United States (including the US portion of Lake Ontario drainage) it is estimated that access to and from potentially 84% of the former habitat of American Eel has been impaired, with the greatest impairment occurring in the North Atlantic region (Maine to Connecticut). In the Canadian portion of the Lake Ontario and St Lawrence River systems, Verreault et al. (2004) estimated that dams prevented, restricted or delayed access to 12,140 km² of potentially suitable habitat in this area.

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. Eels cannot jump over barriers and vertical steps greater than 50%-60% of body length are considered to form impassable barriers (Knights and White 1998). 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 (Tremblay et al. 2011). The ability to bypass structures decreases with size. Eels of all sizes can climb slopes with surface irregularities or vegetation; American Eel have been observed traversing damp substrates such as moss, grass, rocks and cement (MacGregor et al. 2010). However, only small eels (<10cm length), typically elvers, can traverse vertical or near vertical barriers and migration overland in wet areas is only possible in a limited number of cases and for small animals (Legault 1988;

Lamson et al. 2006). Lamson et al. (2006) showed using Sr:Ca otolith microchemistry that a 2.2 m vertical wooden spillway with earthen dam only permitted upstream movement of elvers and not larger eels, whereas a pond with a 5-chamber pool and weir salmonid fishway facilitated upstream movement of eels of larger size. In some situations, eels may end up in ecological traps, accessing habitat upstream of obstructions at small sizes but unable to find downstream passage and subsequently unable to contribute to spawning at larger sizes.

2.2.2. Habitat fragmentation

Loss of habitat associated with large dams is easiest to quantify but habitat fragmentation associated with a large number of small activities, such as improperly installed culverts at road crossings, is more difficult to quantify. For example, based on an inventory of stream crossings within the first kilometer inland above the head of tide in rivers of Nova Scotia flowing into the southern Gulf of St. Lawrence, impediments to fish passage were noted at 47% of the 669 sites studied (Breau 2013). 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), strong currents and steep gradient, and excessive length of structure, which exceed the burst swimming capacity of eels. Upstream movement at structures may also be impeded or obstructed by high velocity currents. Eels move upstream between the Beauharnois and Moses-Saunders dams in Ontario at an average speed of 1.1 km/day, taking at least three migrating seasons to pass both dams (approx. 80 km, Verdon and Desrochers 2003). McCleave (1980) reported on the relationship between distance travelled and swimming speed for European eel elvers exposed to different water velocities. Burst swimming speeds of 7.5 body lengths per second could not be sustained for longer than half a minute (McCleave 1980). Knights and White (1998) state that European eels < 100 mm length are able to swim against currents of 1.5 - 2.0 m s^{-1} and Solomon and Beach (2004) describe burst speeds in European Eels in the 400 – 600 mm length range as 1.25 - 1.35 m s^{-1}.

Eels utilize a range of habitats (Pratt et al. 2014) and show varying growth rates with the slowest growth rates reported from freshwater fluvial habitat, followed by freshwater lacustrine habitat, and highest growth rates in saline waters (Cairns et al. 2014). In several studied areas, seasonal migrations between freshwater and brackish waters have been reported, with eels migrating into freshwater in the fall to overwinter in rivers and migrating downstream in the spring to take advantage of feeding and growth opportunities in saline areas. In Nova Scotia, Newfoundland and Quebec, eels with ready access to brackish or salt waters may undertake downstream migration in spring from freshwater to forage in the salt water environment and migrate back to freshwater for overwintering (Jessop 1987; Jessop et al. 2006, 2009, Thibault et al. 2007b). In the York River on the Gaspé Peninsula, Quebec, 50% of eels trapped and released in the river moved into the estuary for the summer (Hedger et al. 2010). On Prince Edward Island, Cairns et al. (2004) did not find seasonal movements between freshwater and estuarine water and speculated that the head-of tide impoundment may restrict seasonal movements. Some American eels may make seasonal migrations in spring and fall within freshwater areas. In Ontario (Bonnechere River), American eels have been observed moving downstream in the fall from hard clay bottoms to areas in the lower reaches with mud or silt bottoms (MacGregor et al. 2010).

The imperative of these habitat exchanges to eel survival and production are not known but it should be assumed that it is essential for species fitness as it is a general phenomenon observed throughout the species range.

Density dependent responses

Barriers that restrict or impede upstream movement may lead to concentration of eels immediately downstream of the barrier (Wiley et al. 2004; Machut et al. 2007). It is speculated that high density of eels in these regions may increase cannibalism (particularly on elvers), predation, competition for food, disease, and negatively affect eel growth (Haro et al. 2000b; Wiley et al. 2004). In New York, eels that passed < 0.5 barriers km^{-1} had significantly better condition than eels that had to pass more than 0.5 barriers km^{-1} (Wiley et al. 2004). Density dependent effects have been hypothesized as a factor determining the number of eels moving into Lake Ontario from the upper St. Lawrence River with low numbers of eels ascending to Lake Ontario a reflection of low abundance of eels in the St. Lawrence River (Casselman 2003).

Fitness consequences of delays in migration at barriers

Blockages to migration and delays in migration associated with barriers may result in lower growth rates and lower survivals of eels. These responses could result from increased energy expenditures to find upstream and downstream access points and increased energy expenditures during the search for access points, delayed mortality or reduced fitness resulting from injuries of animals moving over barriers, and increased mortality from predators targeting aggregations of eels accumulating below barriers. Predator targeting of prey at the base of dams and at spillways has been reported for other species (ex. feeding on downstream migrating salmon smolts) and this activity would be expected for eels accumulating at barriers. From video records at the Moses-Saunders eel ladders, raccoons were observed chasing eels in the eel ladder and eels killed by raccoons were noted (A. Mathers, Ontario MNR, pers. comm.). Muskellunge, potential predators of eels, were also observed at the foot of the eel ladders (A. Mathers, Ontario MNR, pers. comm.).

Various studies reported on delayed movements of eels associated with barriers (Haro et al. 2000a; Jansen et al. 2007; and references in OWA 2010; Travade et al. 2010). A proportion of eels in the studies did not show any delayed movements however up to 50% were delayed to a maximum of 18 days depending on the site. Notable behaviour from delays included repeated active swimming upstream and returns to the barrier (Haro et al. 2000a; Jansen et al. 2007). A migration study conducted on silver eels at the hydroelectric facility on the Magaguadavic River found downstream movements of many eels were delayed at the dam and tagged fish moved extensively in the reservoir, presumably searching for an exit (Carr and Whoriskey 2008).

Upstream migration over barrier exposes animals to situations not encountered in the water column including exposure to air and predators, and injury from contact with substrate.

Fewer mortality rates and injuries are expected if eels are able to migrate downstream past dams through outlet structures, gates, and spillways rather than through turbines. During downstream passage around turbines, the animals may be killed or injured during free fall. A waterfall height of 13 m was proposed by Larinier and Travade (2002) as the threshold limit for mortality of fish greater than 60 cm. The presence of a pool of considerable depth downstream of the dams would minimize damage during downstream passage (Larinier and Travade 2002).

2.2.3. Impacts from conventional (in dam) turbines

Eels that pass through conventional turbines that operate using a head of water may be injured from a blade-impact, as a result of pressure changes, due to low pressure (cavitation), and velocity differences (shear forces), with blade-impact being the most important (OWA 2010). OWA (2010) summarizes a large number of studies that assess turbine mortality and injury of American Eel. Turbine mortality is reported to be 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. Mortality rate of silvering eels migrating from Lake Ontario and the upper St. Lawrence River passing the Moses-Saunders Generating Station was estimated at 26.4% and at the Beauharnois facilities it was estimated at 17.8% (Verreault and Dumont 2003). In New Brunswick, 100% of tracked eels that passed though the turbines at the Magaguadavic River Dam were killed (Carr and Whoriskey 2008). Most of the studies on turbine related mortality do not consider the delayed mortality associated with injuries or the consequence of these injuries on migration success and successful spawning. Concerns about turbine mortality may extend to areas where tidal generating facilities have been constructed, such as the Annapolis River, Nova Scotia and new initiatives in tidal power generation (DFO 2009b).

2.2.4. Impacts from kinetic turbines

Many small-scale hydroelectric projects that use the natural change in elevation of the water (in a river or due to tides) rather than a dam, reservoir or flooding to create an artificial head are in development. These structures may divert water into a penstock or pipe that channels it to a turbine then back to the river. Other designs do not use penstocks and these kinetic turbines as described in BMP Ontario (2010) are installed in flowing waters with the shaft and blades (turbine) enclosed in a case or in an open blade system in a number of different configurations (internet search for hydrokinetic turbines provides images of a large range and diversity of proposed and tested hydrokinetic turbines). The impacts of these kinetic turbines on fish would be primarily associated with blade impact as there are no pressure or velocity changes associated with their operation. In theory, fish could more readily bypass these turbines as they are not constrained by a penstock or pipe as they approach the structure. However, dependent upon their placement and particularly if placed as arrays, there may still be a high probability of interaction with migrating eels. These structures may still delay migration of eels and the effect of the noise from these structures on fish behaviour requires study.

2.2.5. Ecosystem changes above barriers in manmade impoundments

In addition to physical characteristics of lacustrine habitat created by barriers which differs in many ways from the habitat features of fluvial conditions, there are expected changes in the aquatic faunal communities. The consequences on eel growth rates, survival, and fitness may be positive or negative. In some cases, species composition may change favouring more abundant small prey fish and invertebrates utilized by eels. Substrate characteristics and extent of aquatic vegetation may become more favourable for eels. In other cases, predatory species of fish, frequently non-native, may become established in lacustrine habitat when they would otherwise have been excluded from the fluvial habitat. Examples are the establishment of Smallmouth Bass, Chain Pickerel, and Muskellunge in the headpond above Mactaquac Dam on the Saint John River (New Brunswick).

Table 2.2.1. Summary of physical obstructions threats and associated stress.

General threat	Specific threat	Stress	Causal certainty
Loss of habitat access	Barriers that prevent access to productive habitat	Lower equilibrium population sizes overall, increased density dependent effects including reduced growth rates, lower survival, consequences on sex ratios	Known to occur Access to habitat has been severely impacted in large areas of the species range Density dependent responses are known to occur in culture environments and in natural situations.
	Habitat fragmentation that prevents life stage, annual, and seasonal movements of eels among habitat types	Reduced growth rates and increased mortality due to resource limitations, density dependent effects on growth and survival	Known to occur Habitat fragmentation is known throughout the range of the species associated with the large number of barriers and stream crossings Diverse use of habitats by individual animals within and among rearing areas suggests that access to diverse habitat is required for species wide fitness and persistence.
	Delays in migration	Lower growth rates and lower survivals resulting from energy expenditure, physical injury and predation	Known to occur Hypothesized stress responses: increased energy expenditures to find access points and move around barriers. Injuries and mortalities from falling over barriers observed. Predator targeting of aggregations expected.
Interaction with conventional turbines	Blade-impact, pressure changes (cavitation, gas bubble disease), velocity differences (shear forces)	Immediate mortality and delayed mortality due to injuries	Known to occur Mortality of eels passing through conventional turbines is well studied and factors contributing to mortality rates are well understood. Delayed mortality from injuries is less well known but would be expected.
Interaction with kinetic turbines	Blade-impact, delays in migration	Immediate mortality and delayed mortality due to injuries, increased energy expenditures to avoid structures	Not studied Mortality of eels due to blade strikes well studied in conventional turbines and factors contributing to mortality rates are well understood. Delayed mortality from injuries not known. Delayed migration not studied.
Ecosystem changes in artificial impoundments	Physical and biological characteristics of lacustrine habitat created by barriers differ from those of fluvial conditions	Increased mortality due to changes in physical habitat, prey and predator communities	Known to occur in some areas Changes in predator fish communities that are favoured by lacustrine habitat Deep water habitat created in headponds may not be favourable to eels
		Increased growth rates and survival, increased yield due to favourable conditions	Reported; expected in some situations Growth rate and densities of eel are lower in riverine habitat compared to lacustrine habitat in the same watersheds. Habitat features (substrate, vegetation, prey) in lacustrine areas frequently more favorable for eels

2.3. WATER QUANTITY

The Water Quantity category encompasses the broad class of threats associated with regulation and extraction of water that changes the habitat characteristics and the stress to the individual and/or the population (Table 2.3.1), and may manifest itself as:

- Density dependent effects on growth rates, survival, and condition of eels associated with water regulation and extraction that reduces the amount of available habitat.
- Direct mortality associated with entrainment of water extraction activities.
- Direct mortality associated with stranding and predation due to rapid variations in water quantity due to water regulation.
- Variations in water levels may affect migration success of life stages which in turn can affect survival and reproductive success

Water extractions in rivers and lakes result from urban requirements for drinking water, for irrigation in agriculture, for use in industrial processes (for ex. paper mills), for cooling thermal and nuclear generating stations. Under conditions of high water use demand, water levels in streams and rivers may be reduced to very low levels, reducing the habitat available for eels, leading to reduced growth and higher mortality. Winter drawdowns of reservoirs can remove all available food for juveniles and when these drawdowns are rapid or periodic, these could potentially affect growth and survival of eels. This has been shown for other littoral zone benthivores (Haxton and Findlay 2009). Jurisdictions generally have regulations or water management plans in place to mitigate for excessive loss of habitat due to water extraction but there are examples of water withdrawal projects that resulted in almost complete dewatering of sections of streams (for ex. Charlo River, NB, City of Charlottetown PEI water withdrawals in 2012). The amount of eel producing habitat compromised by these activities will vary with the project and within season and among years.

Entrainment of fish into water intake pipes can also occur but screens and grates placed at the intake of such structures can generally mitigate for this.

Water quantity may also be affected by water regulation schemes, generally associated with management of storage dams for hydro-electric generation and with variations in discharge downstream of hydro-generating facilities. Daily variations and in some cases hourly variations in electrical demand can result in large fluctuations in water levels and discharges due to variable water releases from storage reservoirs (for example in the Tobique River, Saint John River, New Brunswick). Stranding of fish in these situations, especially for eels which burrow in the substrate in the winter may result in mortality. Jessop and Harvie (2003) reported on a possible link between the absence of elvers annually noted at the fishway on the Mactaquac Dam in the Saint John River following on the addition of turbines and a raising of the headpond in 1980 to 1984. They suggested that changes in discharge patterns downstream of the dam may have precluded the upstream migration of elvers to the dam. Due to their limited swimming ability, elvers are most susceptible to impeded migration and stranding due to such variations in water quantity.

Silvering phase American eels leave the upper part of the St. Lawrence River in summer and migrate through the brackish waters of the St. Lawrence River in the fall (Verreault et al. 2012). Analysis of Catch per Unit Effort (CPUE) data from near Quebec City in the St Lawrence River by de LaFontaine et al. (2009) suggests that the median eel capture date in summer was earlier in years with high water level (and flow) and later in years with low water level (and flow). Migration patterns of eels, as inferred from daily catch records in lower St. Lawrence eel weirs, exhibit correlations with some hydroclimatic factors; years of early silver eel migration were associated with high water discharge during the migration period and late migrations were associated with low water discharge (Verreault et al. 2012). de LaFontaine et al. (2009) speculate that delayed seaward movement may subsequently affect gonadal development, arrival of eels at the breeding grounds, time of spawning and larval hatching success in the ocean.

Table 2.3.1. Summary of water quantity threats and associated stress.

General threat	Specific threat	Stress	Causal certainty
Water extraction	Removal of water that reduces productive habitat	Lower equilibrium population sizes overall, increased density dependent effects including reduced growth rates	Known to occur Portions of streams have been dewatered due to water extraction activities. Density dependent responses are known to occur in culture environments and in natural situations.
Entrainment in water intakes	Impellor impacts, pressure changes, impingement on grates	Immediate mortality and delayed mortality due to injuries	Known to occur There are a few reports of this happening at nuclear generating stations and water treatment plants in Ontario (A. Mathers pers. comm.).
Regulation of water levels and discharge	Rapid fluctuations in water levels can result in stranding, displacement downstream, higher than normal discharge prevent migration of life stages	Direct increased mortality due to stranding or displacement downstream	Not reported; expected to occur Eels burrow in substrate during the day and especially in the winter and are susceptible to stranding when water levels are decreased rapidly.
		Changes in water velocity prevent upstream migration of smaller life stages	Reported; expected in some situations Increased discharge from peaking hydro-electric facilities prevent migration of elvers and small bodied eels.
Water level variations due to climate variation	Water level (quantity) variations seasonally and inter-annually	Water level variations effect timing of eel migrations which may reduce reproductive fitness	Evidence from literature that mean dates of migration of silver eels are negatively correlated with discharge. Hypothesized effect only: delays in migration result in reduction in energy reserves required to complete migration to the spawning grounds, resulting in lower survival, lower reproductive fitness.

2.4. WATER QUALITY

The Water Quality threat category encompasses the broad class of threats associated with water chemistry (oxygen, pH), and temperature (Table 2.4.1). The resulting stress to the individual and population manifests itself in numerous ways including direct mortality associated with reduced water quality (for ex. anoxia, low pH).

Based on the diverse habitats occupied by eels and the broad distribution of the species, eels can seemingly tolerate a wide range of salinities (from pure freshwater to full sea water) and a broad range of temperatures (<0ºC to > 30ºC). In terms of oxygen requirements, it has been stated that since eels, in particular elvers, can absorb oxygen cutaneously, they can survive better in moist air than in polluted or low oxygen water (Facey and Van Den Avyle 1987).

The tolerance of American Eel to low pH appears to be related to life stage. Elvers are considered to be less tolerant of acidic waters than older life stages and Jessop (2000) considered that the high mortality rate of elvers in the first season of residence could partly be attributed to low pH, values ranging from 4.7 to 5.0 and periodically as low as 4.2 in the river monitored. In contrast yellow American Eel was the most abundant fish species sampled in streams in Nova Scotia, even when with pH reached 4.5 – 5.0 (Lacroix 1987; Watt et al. 1997). In addition to direct effects of low pH on eels, trophic level effects may be expected if the food base of eels is affected by acidification (Raddum and Fjellheim 2003). It should be noted that the toxicity of low pH waters is enhanced in the presence of dissolved labile aluminum (non-organic form) (Lacroix 1987) with the most affected area being the Southern Uplands located on the Atlantic coast of Nova Scotia (Shaw 1979).

Eutrophication of waters, most generally associated with excess nutrients from agricultural runoff and urbanization, manifests itself most often as nuisance algal blooms. Management programs initiated in the early 1970s succeeded in reducing phosphorus loading to Lake Ontario to counteract the eutrophication of the lake over three decades beginning in the 1940s (Mills et al. 2003). There are ongoing concerns that inputs of nutrients and organic matter from wastewater discharges and farming could reduce dissolved-oxygen levels in some parts of Lake Saint-Pierre (State of the St. Lawrence Monitoring Committee 2008). Benthic blue-green algae that form filamentous (*Lyngbia wollei*) or gelatinous (*Gloeotrichia pisum*) masses were observed in lakes Saint Louis and Saint-Pierre in recent years. These algae are potentially toxic and produce volatile organic compounds that can create taste and odour problems and their presence is enhanced with high nutrient levels, high temperatures and slow currents. The impact of their proliferation on the ecosystem is not well known (State of the St. Lawrence Monitoring Committee 2008).

Eutrophication concerns are not restricted to freshwater. There is a zone of oxygen poor water in the lower estuary of the St. Lawrence River and deep waters of the Laurentian Channel are hypoxic and oxygen levels have decreased over the last 75 years (Gilbert et al 2005). In Prince Edward Island, eutrophic conditions persist in many estuaries and bays that incise coastline (Cairns 2002). The most striking symptoms of this are the excessive blooms of sea lettuce (*Ulva* sp.) that eventually die and decompose leading in many areas to anoxic conditions mostly in July and August. When these events happen, the water turns whitish, accompanied by strong odors and there can be shellfish die-offs in the area (Cairns 2002). Fish that are unable to relocate also die and there are reports of eels in fishing gear dying as a result of such events (D. Cairns, DFO, pers. comm.).

Table 2.4.1. Summary of water quality threats and associated stress.

General threat	Specific threat	Stress	Causal certainty
Water quality	a) Low oxygen resulting in anoxic conditions. b) Low pH from acid precipitation or industrial acidification.	a) Direct mortality in anoxic conditions b) Direct mortality in low pH conditions	Known to occur a) Anoxic events have been reported in estuaries of Prince Edward Island b) Low pH in rivers in southern Uplands of Nova Scotia may result in very high mortalities of elvers

2.5. POLLUTANTS, CHEMICALS AND WASTEWATER

The Pollutants, Chemicals and Wastewater threat category encompasses the broad class of threats commonly referred to as contaminants (Table 2.5.1). The effects of this category of threats are most often expressed as mortality due to secondary causes (such as osmoregulatory failure), and possible effects on reproductive fitness including migration success and quality of reproductive products.

- Direct mortality associated with chemicals (pesticides) and contaminants.
- Delayed mortality associated with contaminants and chemicals as a result of increased susceptibility to secondary stresses (diseases).
- Reduced / compromised reproductive fitness from contaminants that reduce survival of migrating silver eels, compromise the quality of the reproductive products, and lower survival of eggs and larvae.

Brusle (1991) summarized the various studies on effects of pollutants on anguillid species and concluded that eels may be less tolerant to many synthetic compounds than originally believed. The American Eel is particularly susceptible to accumulating contaminants due to its relatively high lipid content, its long life expectancy, its diverse diet, and its ability to live in many diverse aquatic environments including urbanized and industrial areas (Byer et al. 2013b). Nilo et Fortin (2001) provide a synthesis of the studies related to heavy metals (mercury primarily), toxic chemicals, and contaminants of the American Eel. A broad range of contaminants have been detected at elevated concentrations in American eels, particularly in those from the Lake Ontario and the St. Lawrence River.

2.5.1 Toxic chemicals

In Prince Edward Island, there is a documented history of fish kills associated with use of agricultural pesticides beginning in 1966 and that continues into the present (Cairns 2002; Cairns et al. 2012a). Brook Trout and Atlantic Salmon are the species most noted in these reports of kills and although eels have not specifically been noted, the expectation would be that some eels would have succumbed if they were present in those areas.

Dead eels were reported along the shoreline of the St. Lawrence River dating back to the 1960s; in the early 1970s losses were estimated to have been 45 t in 1972, between 91 and 227 t in 1973 and 7 tons in 1974 (Dutil et al. 1987; Nilo et Fortin 2001). In their study, Dutil et al. (1987) concluded that the pathological conditions in the gills of the affected animals were probably caused by pollution in the St. Lawrence estuary. Large mortalities of eels estimated to be in the several tens of thousands were also reported in 1993 in Lac Saint-François; the cause of the mortalities had not been determined (Nilo et Fortin 2001). Despite numerous efforts, the link between these mortalities and a specific chemical has not been made. As indicated by Dutil et al. (1987), silver seaward migrating eels of Lake Ontario and the St. Lawrence are more vulnerable to osmoregulatory problems because they cannot avoid swimming through the polluted waters, they do not feed at that stage and therefore could not replenish the minerals by food intake, and they are unable to absorb chloride through their gills.

Lampricides were first used to control sea lamprey in Great Lakes tributaries in 1958. Boogaard and Rivera (2011) state: “Since then, over 3,000 treatments have been conducted in the U.S. and Canada, and no American eel mortalities have ever been reported to the U.S. Environmental Protection Agency or Canada’s regulatory equivalent, Health Canada. The reporting of adverse incidents (e.g., nontarget mortalities) in the U.S. and Canada is required by pesticide regulations (Federal Register 1997; Department of Justice Canada 2006). Our tests (TFM RQ = 0.21, TFM:1% niclosamide RQ = 0.31; Table 9) and extensive field observations indicate that lampricide treatments pose little risk to American eel.” Toxicity tests using yellow stage American eels indicated the two main lampricides presently used were not acutely toxic to American eels; mortalities were rare among American eels exposed to TFM concentrations up to 5-foled to 7-fold the observed sea lamprey minimum lethal concentration (MLC) depending upon the specific lampricide (Boogaard and Rivera 2011).

2.5.2. Heavy metals

Mercury contamination has been documented in American Eel. Nilo et Fortin (2001) provide a summary of earlier studies of mercury monitoring in eels. In earlier work, mercury concentrations that exceeded the human consumption guidelines were reported in eels sampled from some Bay of Fundy rivers of New Brunswick (Zitco et al. 1971). High concentrations of mercury in eels and other commercially fished species in Ontario and Quebec resulted in an export ban in 1970 and 1971 (Nilo et Fortin 2001). Moreau et Barbeau (1982) analyzed the levels of several heavy metals (cadnium, cobalt, chromium, copper, mercury, manganese, nickel, lead, and zinc) in the muscle tissue of American eels from several locations in Quebec. They found generally high levels of all these elements in American Eel, with higher levels associated with sites of industrial activity. With the exception of two sites (Saguenay and Lac Saint-Pierre), the mercury levels did not exceed the guidelines for human consumption. Mercury levels were high in those two areas due to important inputs of mercury from industry. Hodson et al. (1994) reported that mercury levels had declined in eels from the 1980s. Recently mercury levels measured in water samples from Quebec City indicate an increasing trend since 1995 (Environment Canada 2005). There are no studies that link heavy metals to physiological consequences of American Eel.

2.5.3. Contaminants

Eels from the St. Lawrence River are known to have heavy burdens of mercury, PCBs, pesticides and mirex with levels of PCB congeners in tissues that may be hazardous to eels (Castonguay et al. 1994; Hodson et al. 1992, 1994). Levels of mirex were sufficiently high that a ban on export of commercial fish from Quebec and Ontario was in place in 1982 and 1983 (Nilo et Fortin 2001).

Couillard et al. (1997) first reported on associations between the prevalence of pathological lesions (positive) and parasites (negative) with the level of contamination of eels sampled from the St. Lawrence River. More recently, numerous studies have documented the effects of lipophilic (accumulate in fat tissues) contaminants (polychlorinated biphenyls (PCBs), organochlorine pesticides (OCPs), and polybrominated diphenyl ethers (PBDEs)) on impaired embryonic development of eels (studies referenced in Byer et al. 2013b). It has also been suggested that the accumulation of contaminants is linked to a reduction in lipid content in eels, through various pathways, which may result in impaired spawner quality (Belpaire et al. 2009). However, a direct relationship between the reported effects and a population level response has not yet been established (Byer et al. 2013b).

Byer et al. (2013b) reported that the current concentrations of PCBs, OCPs, and PBDEs in eels are generally below or within the lower range of preceding studies and consistent with a continuing decline of these compounds in biota following the introduction of regulations on their use and manufacture. Although concentrations of PCBs and OCPs in eels captured in Canada were below published guidelines to protect human health, total PCB, DDT, and mirex concentrations were high enough to pose a risk to piscivorous predators (Byer et al. 2013b).

Chlorinated persistent organic pollutants (POPs), dioxin-like chemicals, have been implicated in the collapse of Lake Trout (*Salvelinus namaycush*) from Lake Ontario in the mid-1960s. Based on induction of cytochrome enzymes, American Eel may be as sensitive to dioxin-like chemicals as lake trout (Byer et al. 2013a). Byer et al. (2013a) predict that the maternal transfer of these POPs to eggs would cause embryo-toxicity and impaired recruitment. In addition, there could be added stress to eel embryos because : “eels (1) are longer lived, meaning they have more time to accumulate contaminants, (2) are semelparous, so they do not depurate contaminants during successive reproductive cycles, and (3) concentrate hydro-phobic contaminants during their spawning migration as they consume a large portion of their stored fat for energy" (Byer et al. 2013a, p. 1440). Byer et al. (2013a) found dioxin-like compound contaminant levels in eels to be highest in areas with industrial developments, including those from Atlantic Canada. Based on available guidelines they concluded that the risk to American Eel recruitment was low but these were not based on guidelines derived from eels.

The largest source of three pesticides (atrazine, simazine and metolachlor) used extensively in agriculture and which were detected in the St. Lawrence River is the Great Lakes Basin. Concentrations of these pesticides in the St. Lawrence River were of the same order of magnitude as those measured at Wolfe Island, at the mouth of Lake Ontario (State of the St. Lawrence Report 2008). However, at the Quebec City station, higher levels are observed in summer seemingly due to the application of pesticides on farmlands located in the St. Lawrence lowlands. While the concentrations of pesticides fluctuate greatly on a seasonal basis, no upward or downward trend has been observed since 1995 but at the Wolfe Island station concentrations of atrazine have grown since 1990 (State of the St. Lawrence Report 2008).

The role of contaminants as a possible factor in the decline in recruitment of the American Eel to Lake Ontario and the upper St. Lawrence River was discussed and discounted by Castonguay et al. (1994) due to a review of the timing of the collapse and the history of contamination in this area.

However, the role of contaminants as a continued threat to American Eel cannot be discounted. Specifically for the St. Lawrence River, between 1995 and 2005, there were no upward or downward trends in the quality of the water (State of the St. Lawrence Report 2008). Water contamination by metals and organic contaminants remains low relative to water quality criteria and little change was noted in polycyclic aromatic hydrocarbons (PAHs), which originate from the combustion of wood and fossil fuels, as well as pesticides. However, PBDEs, a group of substances used as flame retardants, show a definite increase.

> "These emerging substances are worrisome since they have properties similar to those of polychlorinated biphenyls (PCBs). They accumulate in the environment and in living organisms and can have toxic effects. Pharmaceutical and personal hygiene products, such as ethinylestradiol, antibiotics (triclosan) and carbamazepine are also a cause for concern because of their potential toxic and endocrine-disrupting effects in molluscs and fish. Lastly, in the majority of cases, concentrations of PCBs and dioxins/furans measured in the Richelieu and Yamaska rivers exceed the quality criteria thresholds for the protection of piscivorous terrestrial wildlife. Consequently, the presence of these bioaccumulative substances in the food chain could result in the contamination of mammals and birds that feed primarily on fish. Of all the Quebec rivers that were investigated, the Yamaska and Richelieu rivers showed the highest concentrations of these substances." (State of the St. Lawrence Report 2008).

Table 2.5.1. Summary of Pollutants, Chemicals and Wastewater threats and associated stress.

General threat	Specific threat	Stress	Causal certainty
Toxic chemicals	Pesticides and other industrial chemicals, pollution	a) Direct mortality due to exposure to pesticides b) Delayed mortality due to osmoregulatory stress associated with pollutants	a) Expected to occur Fish kills occur regularly in Prince Edward Island associated with agricultural practices. b) Known to occur Mortalities in the St. Lawrence River in silver eels attributed to pollution.
Heavy metals	Bioaccumulation of heavy metals in tissues can compromise physiology	Lower growth rates, delayed mortality, reduced reproductive fitness	Expected but not demonstrated Eels carry heavy burdens of heavy metals particularly from heavily industrialized areas but the individual and population level effects are not known.
Contaminants	Bioaccumulation of lipophilic contaminants in tissues including gonads and mobilization of these contaminants during the migratory and maturation phase of eel	Reduced reproduction fitness due to insufficient lipid reserves to complete the spawning migration	Expected but not demonstrated Lower lipid reserves associated with contaminant burdens in European eel No specific studies on American Eel Contaminant burdens in American Eel from St. Lawrence declined in the 1990s from levels measured in the 1980s Contaminant levels in some areas remain high.
		Reduced survival of eggs and larvae	Not measured in American Eel directly Suspected based on studies of other fish.

2.6. HABITAT ALTERATION

The Habitat Alteration threat category encompasses the broad class of threats associated with incursion and deposition of sediments into water courses and modification of habitat through regulated activities (for ex. aquaculture) (Table 2.6.1). The sources of sediments are broad and include urbanisation (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 agricultural ditches, and other land use or water activities where vegetative ground cover is removed or sediments are mobilized. The sources of modification of habitat through regulated activities refer to environmental impacts of aquaculture activities, primarily shellfish aquaculture as practiced in the Maritime provinces. 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.

- Reduced productivity through reduced growth rates, reduced survival resulting from reduced function of habitat and loss of habitat.

2.6.1. Silt and Sedimentation

Erosion of the land masses is a natural and continuous phenomenon, but the rate of erosion and the transfer of sediments to aquatic habitats can be greatly accelerated by anthropogenic activities. Ongoing dredging programs to maintain navigation channels of sufficient depth to allow boat and large ship traffic in the St. Lawrence and smaller rivers and numerous harbours of Atlantic Canada demonstrate the extent of sediment inputs to aquatic habitat. In some areas of eastern Canada, sedimentation of rivers and estuaries can have consequences on economically valuable fisheries resources (Cairns 2002). Sediments constitute a dynamic environment where pollutants are retained and transformed and the re-suspension of sediment can be a major vector of the contamination associated with these materials (State of the St. Lawrence Report 2008).

Eels are particularly susceptible to this habitat alteration threat as they make extensive use of benthic habitat (Pratt et al. 2014). Eels occupy habitats with a wide range of substrate types from boulder and cobble to sand and mud; soft sediments in particular are favoured by eels in some areas and seasons, as animals burrow and conceal themselves within the substrate. They are also frequently associated with aquatic vegetation and eelgrass (*Zostera* sp.) is frequently used as habitat of eels in estuaries.

Sediment inputs can result infilling of interstitial spaces of large substrate and excessive deposition of fine sediments in estuaries (Cairns 2002). Infilling of interstitial spaces among coarser substrate is the negative consequence of sedimentation which is of concern for many freshwater fish species. Excessive sediment inputs in estuaries can result in destruction of eelgrass meadows, habitats which are particularly favoured by eels (DFO 2012; Joseph et al. 2013). In some cases, the input of fine sediments may be beneficial to eels if the sediments are not compacted and eels can burrow into them.

Shoreline erosion is a major concern in the St. Lawrence ecosystem. Between Montréal and Lake Saint-Pierre, the shorelines have retreated by an average of 80 cm per year since the early 1980s, and up to 3 m per year in some locations (State of the St. Lawrence Report 2008). When water levels are high enough to reach the banks, the wash from commercial ships and pleasure boats is one of the main causes of erosion in this sector.

In the St. Lawrence River, Lake Saint-Pierre receives an average of 1.9 cm of sediment each year and in the elongation of the islands, sediment thickness can reach 250 cm (State of the St. Lawrence Report 2008). Located southwest of the Island of Montréal, Lake Saint-Louis receives discharge from the Great Lakes and the Ottawa River. Sandy shoals are formed from the erosion of the banks of Île Perrot and the Îles de la Paix and suspended particulate matter from the Ottawa River forms an accumulation of silty sediment several kilometres wide (State of the St. Lawrence Report 2008).

Dredging activities which take place in large rivers such as the St. Lawrence River and in a large number of harbours and estuaries in the Maritime provinces provide the most obvious example of sediment transport and deposition into water courses. Dredging and the deposition of dredging spoils in the St. Lawrence River are considered to have contributed to the decline and extirpation of the Striped Bass population of the St. Lawrence River (Robitaille et al. 2011). de Lafontaine et al. (2010) speculated that the drop in catches of American eels at two weirs located in the vicinity of the Quebec City bridges immediately upstream of the La Chaudière River were affected by local dredging work and major shoreline activities that occurred in 1966 during the building of the south shore pillar of the Pierre-Laporte Bridge. Dredging may impact eels directly when dredging spoils are deposited on eel habitat. It is also possible that eels that are burrowing in substrate may be subjected to dredging itself although this may be unlikely as dredging takes place in deeper channels to accommodate navigation. Dredging also deepens the channels with resulting increases in water flow which makes the habitats in the navigation channels less suitable due to the depth and water velocity characteristics.

2.6.2. Aquaculture effects on habitat

The majority of shellfish aquaculture activities occur in relatively shallow sheltered areas of bays in the Maritime provinces. DFO (2010b) concluded that there was substantial evidence that shellfish aquaculture activities may increase the deposition of organic matter which can then can alter local benthic habitat and community structure. The magnitude and spatial extent of benthic effects from bivalve culture depended on a number of factors including the nature and total biomass per unit area of reared organisms. Bottom culture generally has a lower potential for impacts than suspended culture due to the greater limitations on biomass per area and access to the water column. Suspended culture however may possibly result in shading which can impact eelgrass (DFO 2012; Vandermeulen et al. 2012).

McKindsey et al. (2006) concluded that overall, bivalves in culture played much the same roles as bivalves under natural conditions. Negative effects are for the most part associated with the greater concentration of bivalves in culture leading to negative effects on the ecosystem due to increased organic loading in the vicinity of the farms and to harvesting in bottom and off-bottom culture. On the other hand, both benthic and vertical structure added for aquaculture may attract mobile species such as eels, with bivalve culture operations functioning more or less like artificial reefs (McKindsey et al. 2006).

Table 2.6.1. Summary of Habitat Alterations threats and associated stress.

General threat	Specific threat	Stress	Causal certainty
Loss and/or degradation of habitat associated with sedimentation	Removal of ground cover, surface hardening, loss of riparian zones, road construction, tilling, bank erosion associated with urbanisation, forestry, agriculture, mining	Lower growth rates, lower survival due to density dependent effects from resource limitation and lower habitat quality	Known to occur Sedimentation of rivers and estuaries is occurring throughout eastern Canada Stress response: expected to occur, not demonstrated.
Loss and degradation of habitat associated with dredging	Removal of substrate, deposition of dredge spoils on fish habitat	Direct or delayed mortality of animals Lower growth rates and lower survival due to degradation of habitat	Known to occur Maintenance dredging of navigation channels and harbours occurs in the St. Lawrence River and in a large number of bays in the Maritimes Impacts on eels not documented.
Habitat alteration associated with shellfish aquaculture	Deposition of organic matter that alters local benthic habitat and community structure	Lower growth rates, lower survival due to lower habitat quality	Negative habitat consequences known Impact on eel growth rates and survival not known.
	Addition of benthic and vertical structures that increase habitat complexity	Improved survival and growth rates due to improved habitat quality and ecosystem diversity	Known: habitat complexity associated with ecosystem diversity Responses of eels not known.

2.7. PARASITES AND DISEASES

The Parasites and Diseases threat category generally encompasses the stress to individual animals and to populations imparted by parasites and disease pathogens (Table 2.7.1). The effects of this threat are most often expressed in terms of reduced growth rates, reduced survival, and reduced reproductive fitness.

- Direct mortality due to diseases which result in physiological compromise.
- Delayed mortality due to reduced growth rates and compromised energy reserves.
- Reduced reproductive fitness due to compromised energy reserves for migration.

Nilo et Fortin (2001) provide a comprehensive synthesis of parasites and diseases reported from American Eel. Overall, 77 genus/species of parasites in eight organism classes were documented. Diverse parasite communities in fish are generally associated with unperturbed environments and there are suggestions that this is the case for the American Eel. Couillard et al. (1997) reported on a negative association between parasite abundance and contaminant concentrations in eels. Nilo et Fortin (2001) also summarize the pathogens which have been identified in American Eel, indicating that the incidence and consequences of pathogens have been more important in cultured systems where animals are reared in high densities than what might otherwise be encountered in natural environments. In the summers of 1986 and 1987, there was a large die-off of eels in the upper St. Lawrence River and Lake Ontario, and viral haemorrhagic septicaemia was suspected; its presence was confirmed in eel mortalities in 2005 (Casselman pers. comm.).

Important negative consequences are frequently expressed in organisms when the parasites and / or pathogens with which they have not co-evolved. The parasite that has raised the most concern for American Eel is *Anguillicola crassus*, the swim bladder nematode whose natural host is *Anguilla japonica* from Asia (Kennedy 2007).

2.7.1. Swim bladder nematode – *Anguillicola crassus*

Anguillicola crassus was first reported from North America in 1995 and it is now considered to be present in a large proportion of the American Eel’s distribution in eastern North America (Nilo et Fortin 2001). In the invasive populations of the new hosts, both the prevalence and the intensities of the parasite are much higher than in those of the naturally affected host coinciding with elevated survival, longevity and reproductive output of the parasite in the immunologically naive novel eel hosts (Kennedy 2007; Wielgoss et al. 2008). *A. crassus* has an indirect life cycle that starts and ends in the anguillid final host swimbladder lumen.

Much of the specific information concerning the pathological effects of the parasite is based upon investigations of infected European eels, including: capillary hemorrhages, bloody fluid and dead tissue of nematodes within the swim bladder, parasitic nodules in the swim bladder, enlarged pneumatic ducts, and thickened swim bladder wall (Kennedy 2007). These 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 (Clevestam et al. 2011). Information from various studies tends to suggest that the prevalence and intensity of *A. crassus* infections are higher in tidal waters than in fresh water (Campbell et al. 2013).

The swim bladder parasite has been identified from eels in a number of rivers in the Bay of Fundy, Atlantic coast of Nova Scotia with high prevalence (42%) in eels sampled from the Bras d’Or Lakes in Cape Breton (Campbell et al. 2013; Denny et al. 2013). For the Cape Breton area, Denny et al. (2013) suggest that the likely introduction of *A. crassus* was through an intermediate host in ballast water as the sites with the highest prevalence and greatest number of heavily infected eels were within 13 to 20 km of the international shipping ports in the area. Although unconfirmed, Denny et al. (2013) also speculate that mortalities of eels reported by aboriginal fishermen in 2008 and 2009 could be attributed to a combination of infection by the swim bladder parasite which compromised the ability of eels to cope with poor water quality.

Table 2.7.1. Summary of parasites and diseases threat and associated stress.

General threat	Specific threat	Stress	Causal certainty
Parasites and diseases	Lowered resistance to endemic parasites and diseases due to environmental stressors (pollution, contaminants)	Lower growth rates, lower survival	Inferred Differences in parasite communities reported from eels with different contaminant burdens Effects to individuals noted in some areas. Population wide effects not documented
	Reduced resistance to non-native parasites and pathogens	Reduced reproductive fitness	Inferred Reduced condition leading to lower reproductive fitness proposed for European eel. No evidence for American Eel.

2.8. CHANGES IN ECOSYSTEMS

The Changes in Ecosystems threat category encompasses the stress to individual animals and to populations imparted by variations in natural ecosystem components (prey, predators) and changes associated with introduction of native and non-native organisms (Table 2.8.1). The effects of this threat can be expressed in terms of variations in growth rate and condition, variations in survival, and changes in habitat availability.

- Reduced growth rates and reduced productivity resulting from impoverished aquatic communities and foodwebs.
- Variations in mortality due to changes in predator communities.
- Variations in growth rate and survival due to competition from stocking of native species.
- Variations in growth rate and survival due to changes in habitat associated with non-native organisms.

Mills et al. (2003) summarize a broad range of ecosystem changes that occurred in Lake Ontario, associated with regulation of anthropogenic inputs of nutrients, fishing, increases in endemic predator communities, and the deliberate as well as unintended introductions of non-native aquatic organisms. Both negative and positive consequences on the natural ecosystem were noted. In particular, Mills et al. (2003) conclude that although oligotrophication resulting from reductions in nutrient inputs favours “recovery” of the lake ecosystem, the ecosystem will differ from its historic structure due to the establishment of non-native aquatic organisms.

2.8.1. Changes in prey communities

There is increasing evidence that the restoration of diadromous fish populations in coastal rivers of eastern North America may well depend on the restoration of the entire diadromous fish community that co-evolved in those watersheds. Diadromous fish species interactions include the transport of marine-derived nutrients (reproductive products, excretion, decomposition of carcasses) into freshwater during their upstream spawning and recruitment migrations (Walters et al. 2009), the influence on habitat by species which construct redds in the spring (lamprey), and the complex interactions in foodweb links consisting of prey selection by key predators during periods of spatial overlap between migrating stages of anadromous fishes (upstream gaspereau migrations may reduce predation pressure by piscivorous fish, birds, and mammals during important downstream migrations of American Eel). American eels have a diverse diet ranging from invertebrates to fish and are known to feed on carcasses of animals. Some river systems have become impoverished of anadromous fish communities as a result of the construction of dams and barriers that prevent the upstream migration of anadromous clupeids and as a result of overfishing. Although there is no direct evidence of a link between impoverished foodwebs and American Eel population dynamics, diminished prey abundance could result in reduced growth rates and lower survival of eels.

2.8.2. Changes in predator communities

Eels have a varied diet and are seemingly resilient to variations in the aquatic prey communities. On the other hand, variations in predators are more likely to have a direct consequence to abundance of eels in both freshwater and brackish areas. Populations of cormorants have increased in Ontario, Quebec and the Maritime provinces since the 1980s (Mills et al. 2003; MRNF 2006). Double crested cormorants have increased in Lake Ontario, however, at no time since the studies of cormorant pellets started in 1999 have eel contributed more than 0.1 % of the diet by number (J. Johnson, USGS, pers com. 2013) Birt et al. (1987) provided evidence of prey depletion in bays proximate to cormorant colonies and eels were particularly frequent in double-crested cormorant diets (Cairns 1998). There is no direct evidence that cormorant predation has resulted in reductions in eel abundance.

Eels are presumably preyed on at sea by a large number of potential predators including whales. Indirect evidence through analysis of persistent organchlorines in beluga whales and various marine prey suggests that eels from the Lake Ontario – upper St. Lawrence are possibly consumed by beluga whales in the St. Lawrence River (Muir et al. 1996). Recently, Béguer-Pon et al. (2013) reported that six of seven satellite tags which had been placed on migrating silver eels from the St. Lawrence River popped up and reported data that were consistent with the eels having been eaten by sharks, presumably porbeagle shark, within the Gulf of St. Lawrence. Although speculative, the authors indicate that a further temporal / spatial link between migrating silver eels and porbeagle sharks may exist as porbeagle shark females migrate to the Sargasso Sea in the winter to pup, an area and period corresponding to the spawning period of American and European eels. The status of porbeagle shark in Canada has been assessed by COSEWIC as endangered and the present abundance of the species was assessed at 12% to 24% of their abundance in 1961 (Gibson and Campana 2005).

2.8.3. Stocking of native fish

Stocking, defined here as the anthropogenic transfer of eels from one location to another, has recently been undertaken with the objective of increasing American Eel abundance and ultimately recruitment to areas with depleted eel abundances. In 2005 to 2008, glass eels were stocked in the Richelieu River, the outlet of Lake Champlain, which is a tributary to the St. Lawrence River (Verreault et al. 2010). A similar program was undertaken in Lake Ontario during 2006 to 2010 (Pratt and Mathers 2011; Pratt and Threader 2011). The goal of these stocking programs was to augment American Eel abundance in productive rearing habitats where naturally recruiting eel abundances were low. The glass eels which were stocked originated from the fisheries in the Bay of Fundy region of New Brunswick and Nova Scotia (Pratt and Threader 2011). Three concerns were considered in these experiments: introduction of unintended diseases and parasites, phenotypic characteristics of the stocked eels relative to natural migrants (growth, sex ratio, migration), and interactions with naturally recruiting eels.

In the Lake Ontario stocking program, the glass eels 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 *Anguillicola crassus* had been detected in eels sampled from Lake Ontario with the suspected source being the stocked eels (T. Pratt, DFO, pers. comm.).

From monitoring activities in Lake Ontario, stocked eels have dispersed throughout the basin away from the original stocking areas and growth rates were good (Pratt and Threader 2011). However, within the stocked eels sampled, there was a high proportion of males (40%). A similar result was noted from the stocking experiment in Lac Morin (Quebec) (Verreault et al. 2009). This difference in sex ratio of the stocked eels compared to naturally recruiting eels could be attributed to: (1) the holding of glass eels prior to stocking, (2) the relatively high densities at the stocking locations, or (3) both factors (Pratt and Threader 2011).

From the Richelieu River experiment, migrating silver eels were recovered from the fisheries in the lower St. Lawrence River and although the sampled and confirmed eels from the stocking program were all females, they were of much smaller size than the eel phenotype from this area (Verrrault et al. 2010). The results from the Richelieu program indicate that stocked eels are capable of maturing, and initiating a spawning migration in synchrony with naturally recruited female silver eels although for the time being, the reason for the smaller size of the female eels is unknown (Verreault et al. 2010).

Stocked eels were not expected to have any adverse interactions with naturally migrating individuals, although no information is available yet to address that concern.

2.8.4. Non-native species introductions and establishment

There have been several introductions and establishment of non-endemic aquatic organisms to eastern Canada. Some of the non-endemic introductions were accidental (sea lamprey to Lake Ontario, zebra mussel) while others were deliberate (alewife and rainbow smelt in the Great Lakes) and they have had profound effects on the ecosystem and fish communities of those areas (Mills et al. 2003). Both negative and positive views of effects on the ecosystem of the establishment of non-endemic species were noted. One of the most dramatic changes in the Lake Ontario ecosystem was improved water clarity resulting from both oligotrophication and the invasion of dreissenids (mussels) (Mills et al. 2003). The role that introduced species played in American Eel population dynamics in the Lake Ontario is not known.

In the Atlantic provinces, green crab (*Carcimus maenas*) mechanically disturb sediments through their digging activities (Locke and Klassen 2007). This disturbance can damage eelgrass by cutting off the shoots and loosening the sediments in which the plant is rooted. Similar effects of green crabs on eelgrass have been noted in Newfoundland (Morris et al. 2010). In Prince Edward Island, green crabs have been a major nuisance species in the American Eel fishery, as green crabs either prevent the entry of eels to fyke nets, or damage eels captured in the nets so that they are unmarketable (Locke and Klassen 2007). By their digging activities, green crab may also disrupt the burrowing behaviours of American Eel.

Beyond the identified effects of green crab on eelgrass habitat and nuisance in the eel fishery, there is no evidence of either individual or population level effects on eel.

Table 2.8.1. Summary of ecosystem changes threat and associated stress.

General threat	Specific threat	Stress	Causal certainty
Changes in prey communities	Impoverished food webs resulting from overfishing or loss of habitat for anadromous species	Lower growth rates, lower survival	Expected Evidence from literature of contributions to freshwater ecosystems of marine derived nutrients. Some rivers in Atlantic Canada have impoverished anadromous fish communities. No evidence of effects on American Eel growth or survival
Changes in predator communities	Reduced resistance to non-native parasites and pathogens	Direct mortality	Evidence from literature (direct and circumstantial) Potential avian predators are increasing in abundance. Potential marine predator populations are at low abundance.
Stocking of native species	Competition with natural migrants, introduction of parasites and diseases, divergent phenotypic characteristics	Reduced growth rates and reduced survival, reduced reproductive fitness	Direct evidence from stocking programs in Canada No differences in growth and presumably survival but phenotypic differences were noted included sex ratio and size at maturity. Consequences on reproductive fitness not known. Suspected source of swim bladder parasite being detected in Lake Ontario eels.
Non-native species introductions and establishment	Changes in community structure	Changes in growth rates, changes in survival	No direct evidence Introduced alewife, goby and mussels in Lake Ontario may provide prey for eels.
	Changes to habitat	Lower growth rates and survival associated with sheltering and feeding disturbances	No direct evidence Green crab can damage eelgrass meadows which eels are known to use extensively. Burrowing behaviour of green crab may disturb burrowing eels, disruption sheltering and feeding activities.

2.9. BOAT AND SHIP TRAFFIC

The Boat and Ship Traffic threat category encompasses the stress imparted by the presence of the structures, the noise they add to the environment, the changes in habitat suitability associated with bow waves and chop, and the potential for strikes with propellers (Table 2.9.1). The effects of the boat and ship threat can be expressed in terms of variations in immediate or delayed survival, growth rate and survival, and changes in habitat availability.

- Direct mortality associated with propeller strikes.
- Delayed mortality associated with propeller strikes and other contacts.

- Reduced growth rates and reduced survival resulting from disturbance of habitats from waves, physical presence and noise.

The threat associated with spills of materials would be encompassed in the category of pollutants, chemicals, and contaminants. The threat associated with vectors of non-native introductions are considered in the category of changes in ecosystems. The threat associated with waves and erosion of shoreline would be addressed under habitat alterations.

Asplund and Univ. of Wisconsin (2000) provide a summary of the mechanisms by which boats can impact aquatic ecosystems including effects on fish. For fish, the threats relate to emissions from motors, contact with hulls and propellers, turbulence and movement.

Pelot and Wootton (2004) summarize the amount of ship traffic by categories of vessel (merchant shipping, commercial fishing and cruise ship transits) in five regions of Eastern Canada (St. Lawrence River, Gulf of St. Lawrence, Bay of Fundy and south, Southeast of Nova Scotia, and Southeast of Newfoundland). Merchant traffic is a significant portion of the total traffic, particularly in the St. Lawrence River whereas fishing traffic is the largest fraction of the traffic in the Gulf of St. Lawrence (Pelot and Wootton 2004). A total of 368,000 traffic records were noted per year in Atlantic Canada, with 12,000 of these recorded for the St. Lawrence River. The St. Lawrence Seaway was opened on April 25, 1959. In the Montreal to Lake Ontario portion of the St. Lawrence Seaway, total vessel transits (upbound and downbound; one transit represents use of at least one lock of the section of the Seaway) during 2003 to 2012 ranged between 2,395 and 3,000 per year (Table 2.9.2) (St. Lawrence Seaway 2013). In 2012, total transits were almost evenly distributed during the months of May to November (Table 2.9.2). Over 2,000 pleasure crafts (motor powered, at least 6 meters in length and at least 900 kg in weight) transit the Seaway locks each year (http://www.greatlakes-seaway.com/en/recreational/pleasure-craft-guide/index.html). Statistics on the number of pleasure crafts operated in any area of Canada were not found.

2.9.1. Mortality and injury from boat contact and propeller strikes

Fish may be entrained through propellers of ships or boats where they can be struck by the blades and subjected to turbulence, shear stress, and rapid changes in pressure (Cada 1990). Injury may occur immediately upon contact with the propeller or may be delayed and increase the susceptibility to disease and predation. Killgore et al. (2011) reported that about 2.4% of entrained fish showed evidence of propeller strikes and that the probability of a fish being struck by a propeller increased with fish length and engine RPM as well as the number of blades, the blade angle, and the cross-sectional area of water passage (Cada 1990). Equally important, Killgore et al. (2011) reported that entrainment lessened at progressively higher values of channel width, depth, and current velocity.

Eels may be entrained in ship propeller streams or strike propellers from pleasure crafts which can travel at high speeds but there is no information on this. Propeller strikes are more likely to occur when eels are migrating and are in proximity to boats and ships at narrow points such as ship locks.

2.9.2. Fish response to sound

Shipping noise is predominant below 100 Hz and wave action predominates at higher frequencies (Olesiuk et al. 2012). Most teleosts lack specialized hearing organs, are only able to detect low frequencies below 500 Hz, including infrasounds below 20-40 Hz, and are commonly referred to as “hearing generalists” (Olesiuk et al. 2012). The American Eel is a hearing generalist species and compared with many other species in terms of auditory acuity, it is relatively insensitive (Tesch 1977). Eels display an escape reaction to sounds of only 50 Hz while at sounds of 400 Hz, they become restive (Tesch 1977). Sand et al. (2000) reported that migratory silver European eels exhibited avoidance reactions to intense infrasound (11.8 Hz).

There is no information on the threats of shipping and boat noise on eel behavior. Boat traffic is extensive in eastern Canada and particularly in larger rivers and bays with high human population densities.

2.9.3. Fish response to shading and movement

The eel is negatively phototactic, preferring to shelter/burrow in the daytime and becoming active at night (Tesch 1977). Eels respond negatively to artificial light sources (Patrick et al. 1982) although use of light barriers to deflect eels away from hydro facilities is not very effective (OWA 2010). Eel response to overhead movements of boats and ships is not known although their dominant sheltering behavior in daytime may minimize any impacts of moving forms and shading on individual behavior.

2.9.4. Impacts of traffic on eel habitat

Waves resulting from ship and boat traffic will modify the water circulation, and this will be most acute in shallow areas and as waves move to shore. Wave action increases turbidity in shallow and nearshore areas. Waves also move substrate, particularly fine particulate matter, and result in changes in bottom configuration. The effect on eel habitat is not known but the potential threat would be more important in areas with high boat traffic, narrow channels, and shallow waters.

Table 2.9.1. Summary of boat and ship traffic threat and associated stress.

General threat	Specific threat	Stress	Causal certainty
Boat and ship traffic	Entrainment and strikes from propellers	Direct mortality and delayed mortality due to injuries	Evidence from literature for a large number of fish species in river channels. Boat and ship traffic is extensive in eastern Canada. No evidence of effects on American Eel.
	Underwater sounds	Behavioural changes that reduced growth and survival	Eels are responsive to low frequency sounds in the range generated by boat and ship traffic. No evidence of disturbance of eels and impacts on growth and survival.
	Movement and shading	Behavioural changes that reduced growth and survival	Eels are negatively phototaxic, shelter/burrow during the day. No evidence of effects on eels, likely negligible due to daytime sheltering behavior.
	Waves modify substrate	Displacement from habitat, loss of habitat	Waves increase turbidity and mobilize substrate in shallow areas. Effects on eel habitat not examined.

Table 2.9.2. Total transits of vessels in the Montreal – Lake Ontario portion of the St. Lawrence Seaway for 2003 to 2012 and by month during 2012. Data were extracted from St. Lawrence Seaway (2013).

	Total	In 2012	
Year	transits	By month	Total transits
2003	2,579	March	69
2004	2,683	April	250
2005	2,695	May	339
2006	2,942	June	341
2007	2,878	July	301
2008	2,703	August	313
2009	2,395	September	323
2010	2,728	October	355
2011	3,000	November	404
2012	2,975	December	280

2.10. UNDERWATER ELECTRIC CABLES

The Underwater Electric Cables threat category encompasses the stress imparted by the electromagnetic fields resulting from underwater installations of transmission cables (Table 2.10.1). The effects of the underwater electric transmission cables can be expressed in terms of variations in behavior (migration) which can affect reproductive fitness and changes to habitat availability. Effects on habitat would be considered under habitat alterations.

- Reduced survival and reduced reproductive fitness associated with effects on migration and orientation.

Power transmission cables have been installed along the bottom of freshwater, estuarine and marine areas. These transmission cables, AC and DC, may possibly introduce electromagnetic fields (EMFs) into the aquatic environment. It is common practice to block the direct electric field from the external environment by using conductive sheathing with the result that residual effect are the magnetic field and the resultant induced electric field (Normadeau et al. 2011). For both AC and DC cables, the magnetic field is strongest directly over the cables and decreases rapidly with vertical and horizontal distance from the cables, variations depending upon voltage, orientation of the cables, burial depth if any, and spacing between parallel cables (Normandeau et al. 2011) Possible factors and responses of eels, as summarized in Normandeau et al. (2011) to EMF include sensitivity to electromagnetic fields that may affect navigation.

2.10.1. Effects on migration and orientation

The following are summaries from Normandeau et al. (2011) of their review of literature on effects of EMF on eels. Rommel and McCleave (1972, 1973) report that eels were electrosensitive, that they could use such information for orientation, and that the predicted geo-electric fields in ocean currents of the Gulf Stream were within the range of sensitivity for American Eel and could be used for long-distance migrations. McCleave and Power (1978) concluded that the orientation of elvers could be influenced by electric fields of the magnitude generated by major ocean current systems. Richardson et al. (1976) reported that locomotor activities of the American Eel were not affected by extremely low frequency electric or magnetic fields (60 to 75 Hz of 0.07 V/m or 0.7 V/m and 0.5 gauss).

Westerberg and Lagenfelt (2008) tracked acoustically tagged European eels and described their behaviour relative to an underwater transmission cable. They indicated that swimming speed was significantly lower around the cable than north or south of the cable but the physiological mechanisms explaining the phenomenon are unknown. Gill and Bartlett (2010) reviewed the literature on possible effects of undersea cables and underwater noise from marine wave and tidal power developments and concluded that based on current knowledge EMFs from subsea cables and cabling orientation may interact with migrating eels if their migration routes take them over the cables, particularly in shallow waters (<20m). The effect on eels could be a trivial temporary change in swimming direction, or potentially a more serious avoidance response or delay to migration but the biologically significant effect could not be determined.

DFO (2009b) concluded that there was considerable uncertainty regarding the effects of EMFs on marine organisms including eels and that organisms that spend all or part of their life cycles in, on, or close to the benthos may be particularly at risk due to their physical proximity to the EMF source and thus stronger field strengths.

Table 2.10.1. Summary of underwater electric cables threat and associated stress.

General threat	Specific threat	Stress	Causal certainty
Underwater electric cables	Introduce electromagnetic fields (EMFs) into the aquatic environment	Reduced survival and reduced reproductive fitness associated with effects on migration and orientation	Evidence from literature that eels are sensitive to electromagnetic fields. Elver and adult stages could use these for orientation and migration. No evidence of effects on American or European eel but high uncertainty.

2.11. OIL AND GAS EXPLORATION

The Oil and Gas Exploration threat category encompasses the stress imparted by the use of seismic technology for exploration and mapping (Table 2.11.1). The effects of seismic noise can be expressed in terms of variations in behavior (migration) which can affect reproductive fitness and direct mortality particularly of younger life stages. Effects on habitat would be considered under habitat alterations.

- Reduced survival and reduced reproductive fitness associated with effects on migration and orientation
- Direct mortality, particularly of younger life stages.

Oil and gas exploration activities are widespread throughout the territorial seas of eastern Canada. Seismic surveys are the principle method of exploration and can operate over extensive areas for lengthy periods of time. Briefly, these surveys use a series of air guns towed behind surface vessels to generate loud (235-256 dB), low frequency (5-300 Hz) pulses (10 msec) of sound that are directed towards the bottom. Marine organisms immediately below the array air guns receive more sound with the intensity of the sound declining with distance from the source.

American eels are potentially susceptible to exposure to the generated sounds as recruiting leptocephali and elvers, migrating silver eels and in the particular circumstance of exploration activities in sheltered waters as yellow eels.

Sounds in the range 200-205 dB have been shown to elicit a startle response at ranges of 100-300 m suggesting that fish could move away from the source. DFO (2004) concluded that the ecological significance of such effects is expected to be low, except when they may lead to a dispersion of spawning aggregations or deflection from migration paths.

Studies using other fish species have shown that exposure to the pulses of sounds can result in injury and death to fish eggs and larvae (Kastyuchenko 1973) and adults (McCauley et al. 2003). However, injury and death is most pronounced at short distances (<2 m) from the sound source. DFO (2004) concluded that overall, exposure to seismic sound is considered unlikely to result in direct fish mortality.

The specific effects of seismic surveys on American Eel are not specifically known. There are no indications that American eels occur at sea in densities where their encounter during seismic surveys could result in harm to a great number of individuals.

Table 2.11.1. Summary of oil and gas exploration threat and associated stress.

General threat	Specific threat	Stress	Causal certainty
Oil and gas exploration	Seismic noise	Reduced survival and reduced reproductive fitness associated with effects on migration and orientation	No evidence that American Eel (glass eels, elvers, silver eels) occur at sea in densities where their encounter during seismic surveys could result in changes to migration and orientation
		Direct mortality, particularly of younger life stages	No evidence that leptocepahli and glass eels at sea in densities where their encounter during seismic surveys could result in harm to a great number of individuals

2.12. SCIENTIFIC RESEARCH

The Scientific Research threat category encompasses the disturbance, harm and mortality that could result from monitoring and research activities directed at eels or resulting as bycatch in monitoring activities for other species (Table 2.12.1). The effects of this threat can be expressed in terms of immediate mortality, delayed mortality resulting from injuries, reduced growth rate and lower survival due to displacement from habitat and disruption of feeding, sheltering or migration activities.

- Immediate mortality resulting from directed lethal sampling or incidental during capture and processing activities.
- Delayed mortality resulting from injuries incurred during capture, and processing.
- Reduced growth rates and lower survival resulting from stress associated with displacement from habitat, disruption of feeding and sheltering activities, and delays in migration.

American eels are sampled using a wide variety of fish trapping apparatus including dipnets and habitat traps for elvers, fyke nets and trapnets for all life stages, rotary screw traps for downstream migrants, at counting fences and traps, by electrofishing, and others. Over the diverse range of research activities, eels not lethally sampled have been measured, weighed, anesthetized, fin clipped, had otoliths marked with oxytetracylene by immersion, externally marked by immersion staining, externally cold or hot branded, tagged with jaw rings, tagged with internal passive induced transponders (PIT), surgically implanted acoustic tags, and external satellite pop-up tags and released. Although eels are very robust to capture in live traps and handling, they are susceptible to be accidentally injured or killed during monitoring and research programs.

It should be possible for jurisdictions to quantify the number of eels which are sacrificed or accidentally die as part of directed monitoring and research programs. Relative to the number of eels which are harvested in directed fisheries or lost to fish passage mortalities, the numbers are likely quite low.

Electrofishing is a well-established capture technique in fisheries science but electroshocking can cause internal injuries to fish. A number of indices of American Eel from the Maritimes provinces are derived from catch rates of eels in electrofishing programs targeting salmonid juveniles (Pratt and Mathers 2011; Cairns et al. 2007, 2014). Pratt and Threader (2011) surveyed the survival of stocked eels using a boat electroshocker set at 60 Hz. Reynolds and Holliman (2004) report on a study to assess the extent of injuries to American Eel captured with electrofishing. American eels are at high risk for injury because of their high vertebral count; spinal damage occurred in 60% of the electroshocked American eels in their study and most electroshocked American eels had multiple spinal injuries (Reynolds and Holliman 2004). Risk of injuries increased with increasing electric frequency setting and with size (length) of the eel. A high incidence of injury was noted at 30-Hz pulsed DC, the setting used in their study, and they recommended a lower setting, such as 15 Hz, to reduce injuries (Reynolds and Holliman 2004). No documentation of injuries of eels during most monitoring programs is provided. Pratt and Threader (2011) took radiographs of ten eels which had been sampled in their study and there were no signs of vertebral compression, misalignment, and fracture or separation in the eels examined; they attributed this result to the smaller sized eels which were targeted in their study (~ 30 cm or less) compared to the large eels (>90 cm) studied by Reynolds and Holliman (2004). The impact of monitoring programs using electrofishing can be assessed in each jurisdiction, the numbers are likely very low relative to the total number of eels in the area.

All the capture and sampling programs result in the individual animals being removed from their habitat, held prior to sampling, and subsequently released at a time and location which disrupts their “normal” activity. Some of the live trap sampling gears are fished once a day and after handling and frequently monitoring can result in delays of migration (Jessop 2000) and enhanced exposure to predators. The effects on growth rates and other life history processes from monitoring activities are difficult to assess.

Table 2.12.1. Summary of scientific research threat and associated stress.

General threat	Specific threat	Stress	Causal certainty
Scientific research	Directed lethal sampling or incidental mortality from monitoring activities	Direct mortality	Known to occur in all jurisdictions in eastern Canada. Number of animals killed could be quantified.
	Injuries to animals which are captured and sampled and released	Delayed mortality	Expected to occur in all monitoring programs. Evidence of injuries associated with electrofishing. Evidence of delayed mortality is rarely available except for instances of determining short term (days) survival associated with marking activities. Effects are difficult to quantify.
	Displacement of animals from habitat, disruption of feeding and sheltering activities, delays in migration	Changes in growth rates, changes in survival	No direct evidence Monitoring activities displace eels from their natural habitat, hold them in live gear for extended periods of time (24 hr), are released back to water at times of day which may increase predation, delay the migration of animals which are in that mode. Effects on growth and survival are difficult to quantify.

2.13. CUMULATIVE EFFECTS

The majority of the threats above may cumulate spatially and / or temporally.

The cumulative effects of reduced access to habitat, high exploitation in the Lake Ontario fisheries and the construction of hydroelectric facilities in the 1950s contributed to the decline in silver eel production from this area (MacGregor et al. 2008, 2010). Silver eels migrating from Lake Ontario are exposed to potential mortality from 1) passage through the turbines at the Moses-Saunders Dam, 2) passage through the turbines at the Beauharnois Dam, 3) exposed to pollutants, environmental stress and ships in the upper St. Lawrence River, 4) to possible capture in various commercial fisheries of Lac St. Pierre, 5) to possible capture in the silver eel fisheries of the lower St. Lawrence River and estuary and 6) consumption by a variety of predators in the Gulf of St. Lawrence.

Although the annual removals of yellow and silver eels in the fisheries of the southern Gulf of St. Lawrence are less than 10% of the estimated standing stock biomass of the corresponding size ranges, yellow eels are exposed to the fishery over many years prior to maturing and leaving as silver eels. A 10% fishing rate on a stock of fish and an exposure of individual animals to the fishery for five years and ten years results in a cumulative exploitation rate of 41% and 65%, respectively.

2.14. CLIMATE

Although not treated as a threat, climate variations may have consequences on eel reproductive dynamics, early ocean life stages, recruitment to continental areas, growth, and survival and may ultimately limit species abundance and persistence. Some climate variations may be attributed to anthropogenic activities but in this analysis, it is the end result that is of concern rather than the source. Climate can profoundly affect water levels in rivers through seasonal and annual variations in precipitation (see Water Quantity) but the consequences of climate variation may be most acute in the ocean and related to the spawning and early life stages (Table 2.14.1). Specifically,

- Warm sea temperatures may result in reduced survival of leptocephali due to food limitations, and
- Variations in ocean circulation patterns may result in reduced survival and recruitment to North America, particularly to the northern areas.

As summarized by Pratt et al. (2014), silver eels migrate from the continent in the fall and are presumed to arrive in the Sargasso Sea and spawn in early winter. Silver eels do not feed during their spawning migration. the American Eel spawns in the Sargasso Sea in early winter. After yolk sac absorption, early feeding is critical for leptocephali. Recruitment of glass eels to the coast begins with advection of larvae into the Gulf Stream, which transports them north and east along the coast of North America and during the winter and summer at sea post metamorphosis they detrain from the Gulf Stream and recruit to the coast using selective tidal transport (Castonguay et al. 1994; McCleave and Wippelhauser 1987). Elvers arrive early in the spring in the southern areas of Bay of Fundy and the Atlantic coast of Nova Scotia (Jessop 1998).

Knights (2003) suggested that starvation may be an important dynamic of leptocephali survival. Bishop and Torres (2001) conclude that leptocephali are obtaining their energy requirements from two potential sources of food, dissolved organic matter (DOM) and particulate organic matter (PO). Bonhommeau et al. (2008) proposed using primary production as a proxy for leptocephali food due to a strong demonstrated linear relationship between these two components. Further, in an interest to examine a longer time series, the authors used sea temperature as a proxy for primary production. In the Sargasso Sea area, warming inhibits vertical mixing and reduces production such that when sea temperature increases, primary production decreases (Bonhommeau et al. 2008).

Bonhommeau et al. (2008) describe significant negative correlations between several glass eel recuitment indices for the European Eel and temperature in the Sargasso Sea with high recruitment indices noted during a cold phase. They also report on evidence of three phases of Sargasso Sea temperatures, a colder phase before 1980 with a mean temperature of 21.4ºC, a warmer phase afterward (mean temperature of 22ºC) ,with warmer conditions yet after 1999. They concluded that variability in glass eel recruitment was linked to food availability which is determined by the extent of vertical mixing driven by sea temperatures.

No such link has been made between recruitment to North America and food availability / sea temperature in the Sargasso Sea. However, Zhu et al. (2013) recently reconstructed the recruitment series of eels to the upper St. Lawrence and Lake Ontario into cohorts. The first full cohort that could be estimated from the time series is for 1972 (age 3 at the fish ladder with counts beginning in 1975). Except for the 1972 cohort which was very weak, the next lowest abundance value and the one that begins the progressive decline to the present is the 1979 cohort which corresponds to the shift period reported by Bonhommeau et al. (2008).

Castonguay et al. (1994b) concluded that it seemed improbable that decreased larval production could account for the observed differences in abundance trends between the north and south portions of the range of the American Eel. However, they do raise the hypothesis of an Atlantic-wide cause due to ocean climate which could explain the synchronous reported decline in European and North American eel species. The main hypothesis proposed was that the recruitment decline was linked to a reduction in the speed of the Gulf Stream. Although Castonguay et al. (1994b) did not have evidence of a reduction in the speed of the Gulf Stream, they refer to a shift northward of the northern boundary during the 1980s and that these shifts have been linked to changes in the speed of the stream. The possible consequence of changes in ocean circulation could include an increase in the proportion of larvae that metamorphose further south and are therefore a reduced number of larvae available for the northern areas. Another possible consequence is that larvae reaching the northern areas have missed the optimum period and location for metamorphosis and are lost to the recruiting component. Both of these mechanisms are consistent with the observations of reduced recruitment to northern areas and sustained or increasing recruitment to the other areas of the species range. Knights (2003) considers that the prolongation of migration (advection mechanism) enhances starvation and predation losses.

Friedland et al. (2007) indicated that they found evidence of linkages between environmental changes in the Sargasso Sea and recruitment of European Eel, albeit they used only one index of glass eel recruitment. They state that European Eel recruitment may be responding to North Atlantic Oscillation (NAO) forced changes in fronts and currents but they do not discount the link between these physical parameters and food production. Bonhommeau et al. (2008), based on an analysis of a larger number of recruitment indices concluded that ocean circulation was not an important driver of glass eel recruitment to Europe.

Kettle et al. (2008) reported on a significant negative correlation between glass eel catches and the NAO index lagged by 0–2 years and that this was consistent with the hypothesis that the positive NAO phase had an adverse impact on the larval survival in and migration from the Sargasso Sea spawning location, one year prior to the arrival of the glass eels in Europe and North Africa.

Dutil et al. (2009) indicate that American Eel glass eels face harsh environmental conditions when entering the Gulf of St. Lawrence in May at Cabot Strait: near surface temperatures < 5ºC, complex mixing, stratification and near-surface circulation patterns, and <0ºC water in the intermediate layer which probably precludes diel migrations between surface waters and the bottom of Cabot Strait. How variations in these conditions affect migration rates and survivals is unknown but catch rates of glass eels and elvers at various locations in the Gulf of St. Lawrence are much lower than rates along the southern portion of the species range, including the Bay of Fundy and Atlantic coast of Nova Scotia.

Although starvation may be an important dynamic of leptocephali survival, the starvation versus advection debate in relation to eel dynamics is unresolved (Knights 2003).

Table 2.14.1. Summary of variations in oceanographic conditions and associated stress.

General characteristic	Specific characteristic	Stress	Causal certainty
Sea temperatures in Sargasso Sea	Warm sea temperatures result in reduced food availability for leptocephali	Lower survival due to starvation from food limitation	Evidence of warming sea temperatures in Sargasso Sea. Evidence from literature of a negative correlation between glass eel recruitment indices and sea temperature in the Sargasso Sea. Not examined for American Eel.
Variations in physical oceanographic features	Variations in ocean currents effect the recruitment rate overall and differentially to regions of North America	Lower survival and recruitment overall and more noticeably to the northern regions of North America	No direct evidence based on field samples of this recruitment dynamic. Divergent trends in recruitment indices between southern regions and northern regions are consistent with this mechanism. Evidence of changes in oceanographic conditions in the Sargasso Sea and in some features of ocean circulation that could affect recruitment if the hypothesis is correct.

3. CLASSIFICATION OF LEVEL OF CONCERN OF THREATS

This section of the document describes how the level of concern of the threats is qualified. The assessment consists of determining the magnitude (severity), extent (spatial), and the frequency (temporal) of the threat and causal certainty of each threat to American Eel. The assessments are summarized in tables with the following categories.

- **Threat Category**: As described in the narrative, the threat category corresponds the activity or process (natural and anthropogenic) that has caused, is causing, or may cause harm, death, or behavioural changes to individuals and to the species overall; or the destruction, degradation, and/or impairment of the habitat to the extent that population-level effects occur.
- **Specific Threat**: The specific activity or process causing stress to American Eel in the geographic area. Stress is defined as changes to ecological, demographic, or behavioural attributes of populations leading to reduced viability.
- **Level of Concern**: Signifies the level of concern for species persistence if a threat remains unmitigated. The assessment of the level of concern is based on the evaluation of all the information in the table with an emphasis on the extent of the threat (number of populations or area occupied by the species likely to be affected) and the level of severity. The assessment must also be guided by the knowledge of the link between the threat and the stress on the individual animal or the species. When causal certainty is very weak, the level of concern may be expressed as unknown.
    - Very High: threat will lead to substantial declines in abundance or loss of populations in the absence of mitigation.
    - High : threat likely to lead to substantial declines in abundance or loss of populations in the absence of mitigation

- Medium : threat likely to limit populations to low abundance and thus increase extinction risk
- Low : threat may lead to slightly increased mortality but are expected to have a relatively small impact on overall population viability.
- Unknown : In cases for which the severity is uncertain and there is negligible evidence of causal certainty. This level of concern should not be interpreted as negligible. Rather it implies that further studies may be warranted.

To facilitate the assessment of level of concern, a matrix with location / extent and severity dimensions is used (Table 3.1).

- **Location or Extent**: The description of the spatial / population scale extent of the threat in the geographic area of the population under consideration. Where possible, the actual proportion of the area or population interaction with a specific threat is given in brackets. In the fishery threat example, if there are commercial fishing gears in 40% of the rivers and estuaries in the area, then the extent of this threat would be assessed as high.
  - Low : < 5% of area or population interaction
  - Medium : 5-30% of area or population interaction
  - High : 30-70% of area or population interaction
  - Very High : > 70% of area or population affected.
- **Occurrence and Frequency**: This component describes the temporal feature and the temporal extent of the threat.
  - **Occurrence** :the time frame of the threat assessed as
    - Historical (H): a threat that is known or is thought to have impacted American Eel in the past and the activity may or may not be ongoing. For the fisheries example, directed commercial fisheries for eel occurred in the past in Lake Ontario but have been closed since 2004.
    - Current (C): a threat that is known or thought to be impacting the population and where the activity is ongoing. This could include situations in which the threat is no longer occurring but the population-level impacts of the historical threat are still impacting the populations. An example of this is mirex contamination in the Upper St. Lawrence Area. The source of mirex input to the environment has ceased but the compound is still present in the environment and in animals and therefore could still be of concern.
    - Anticipatory (A): a threat that is not presently impacting American Eel but may have impacts in the future. This includes situations where a current threat may increase in scope. For example, there are a number of existing underwater electric transmission cables in eastern Canada and there are proposals for new projects in new areas.
  - **Frequency**: Description of the temporal extent of the threat over the course of a year as seasonal, recurrent, or continuous. For example, fisheries are seasonal threats, silt and sediment threats from land use activities are recurrent threats, and contaminants in the environment are continuous threats.

- **Severity**: Describes the degree of impact a given threat may have or is having on American Eel. This is assessed on the basis of the nature of the threat and possible magnitude of population-level change.
    - Negligible: no measurable impact on survival or recovery
    - Low: little change in population productivity is expected. It may amount to < 5% reduction in spawner abundance. It is unlikely to jeopardize the survival or recovery of the population
    - Medium: moderate loss of population productivity. It may amount to 5-30% reduction in spawner abundance. It will likely jeopardize the survival or recovery of the population.
    - High: substantial loss of population productivity. It may amount to 30% - 70% reduction in spawner abundance. It will jeopardize the survival or recovery of the population.
    - Extreme: severe population decline with the potential for extirpation. It may amount to >70% reduction in spawner abundance.
    - Unknown: There is no information from the species, or related species with which to determine the severity of the threat. General principles suggest this could be a threat as it is known in other contexts. An example may be increased UV radiation from ozone layer depletion.
- **Causal Certainty**: Two-part definition. Part 1: Reflects the strength of the evidence linking the threat (i.e. the particular activity) to the stresses (e.g. changes in mortality rates) affecting populations of American Eel in general. As such, evidence can come from studies on any American Eel or even European Eel. Part 2: Reflects the strength of the evidence linking the threat to changes in productivity for American Eel in the specific geographic area. Causal certainty is qualified as follows:
    - Negligible: Has not been studied for the species and is only hypothesized. For example, evolutionary consequences of stage / size selective fishing.
    - Very low: Unsubstantiated but plausible link between the threat and stresses to American Eel. For example, effects of contaminants on reproductive fitness.
    - Low: Plausible link with limited evidence that the threat has stressed American Eel. For example, the role of oceanography on recruitment of glass eels to North America.
    - Medium: There is scientific evidence linking the threat to stresses to American Eel. For example, the impact of the swim bladder parasite.
    - High: Substantial scientific evidence of a causal link where the impact to populations is understood qualitatively. For example, loss of habitat access due to barriers and habitat fragmentation.
    - Very High: Very strong scientific evidence that stresses will occur and the impact to populations is understood quantitatively. For example, mortality associated with passage through turbines or directed fishing mortality.

Table 3.1. Scoring matrix for level of concern based on severity and extent of occurrence scores.

Level of Concern					
Extent of occurrence	**Severity**				
	Negligible	**Low (<5% decline)**	**Medium (5-30% decline)**	**High (30-70% decline)**	**Extreme (>70% decline)**
Low (<5%)	Low	Low	Low	Medium	Medium
Med (5-30%)	Low	Low	Medium	Medium	High
High (30-70%)	Low	Medium	Medium	High	High
Very High (> 70%)	Low	Medium	High	High	Very High

4. REGIONAL ASSESSMENT OF THREATS

This section provides an assessment of the threats in the five jurisdictions of eastern Canada (Ontario, Quebec, southern Gulf of St. Lawrence, Newfoundland and Labrador, Atlantic coast of Nova Scotia / Bay of Fundy). A summary table of threats is provided by jurisdiction and supporting narrative is provided for those threats with a level of concern assessed as medium and high, or for other threats where a narrative was considered important to assist in the understanding of the scoring.

The overall summary of threats assessed as medium or high concern for the five regions is summarized in Table 4.1.

Table 4.1. Summary of threats assessed a level of concern score of medium or high in the five jurisdictions of eastern Canada.

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 (adult)	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

4.1 ONTARIO

The American Eel in the province of Ontario was listed as “Endangered” under the Ontario Endangered Species Act (ESA 2007). In the draft recovery strategy for the American Eel in the province of Ontario, the following significant threats were identified:

> “The cumulative effects of eel mortality during downstream migration due to hydroelectric turbines, reduced access to habitat imposed by manmade barriers to upstream migration, commercial harvesting in jurisdictions other than Ontario, and habitat destruction, alteration and disruption are among the most significant threats to the survival and recovery of the American Eel in Ontario.” (MacGregor et al. 2010; p. iv).

In the threats assessment conducted for this review, commercial fisheries in the St. Lawrence River, threats from physical obstructions (loss of habitat, habitat fragmentation, turbine mortality) and non-native species invasions were assessed at medium or high levels of concern (Table 4.1).

4.1.1. Directed Silver Eel Commercial Fisheries in the St. Lawrence River

A description of fisheries in Ontario is provided by Mathers and Pratt (2010). Silver eels emigrating from Lake Ontario were historically and are currently exploited in the commercial fisheries in the St. Lawrence River in the province of Quebec. The exploitation rate of this fishery was estimated at 25% in 1996 and 20% in 1997, and due to the similarity in gear deployments and effort over time, these rates were considered to be representative of the exploitation rates over the recent 30-year time period (Caron et al. 2000). Eels from Lake Ontario were estimated to have comprised between 60 and 65% of the total harvest during that period (Caron et al. 2003; Verreault and Dumont 2003).

In 2009, 46 of 67 silver eel commercial fishery licences in the lower St. Lawrence estuary were bought out (DFO 2010d). The exploitation on silver eels following this reduction in fishing effort was estimated at 10.5% (G. Verreault, MRNF, pers. comm., 2011 (cited in COSEWIC 2012)).

Further reductions in fishing effort occurred between 2002 and 2007 when 36 of 42 commercial hoop net fishing licences, targeting mostly yellow eels were bought out from the Lac St-Pierre area, an enlargement of the St. Lawrence upstream of Trois-Rivières (DFO 2010d). There are no estimates of exploitation rates in this fishery but the reductions in effort should have contributed to reducing the exploitation on eels from Lake Ontario.

As a result of the reduction in effort but the continued exploitation of silver eels from Ontario in this fishery at a rate >10%, the severity was scored at medium. As all the migrating silver eels from Ontario are vulnerable to this fishery, the extent was scored as very high which results in a level of concern scored as high.

4.1.2. Physical Obstructions

<u>Loss of habitat</u>

There are at least 953 dams within the eel's historic range in Ontario (MacGregor et al. 2010). Only one dam currently has provisions to encourage upstream migration of eels. These barriers block upstream access to watershed, increasing densities below the barriers leading to density-dependent impacts (Stacey 2013). Current population impacts are considered to be high (substantial loss of productivity, and to jeopardize recovery) and when combined with the extent of the threat (high) results in a level of concern which is high.

<u>Habitat fragmentation</u>

In addition to the identified dams, there is a high human population in the Lake Ontario and in the Ottawa River with corresponding networks of roads and various stream crossings. No quantification of this threat was done in this exercise but in other regions, this component was considered to affect a large proportion of the habitat accessible to eels (high). The severity was assessed as low in Newfoundland and medium in the southern Gulf of St. Lawrence which reflects differences among the regions in the known heterogeneity of habitat use made by eels (freshwater versus brackish, seasonal movements). It was assessed for Ontario as low because all the habitat is freshwater although there is some evidence of seasonal movements between habitat types (MacGregor et al. 2010). Combining the extent and severity scores results in a level of concern which is medium for this threat.

<u>Mortality from turbines</u>

There are 87 hydroelectric facilities within the historic range of eels in Ontario, and 30 within the post-2000 range (MacGregor et al. 2010). On the St. Lawrence River, cumulative turbine mortality of eels at the Beauharnois and Moses-Saunders facilities during their downstream spawning migration has been estimated to be 41% (referenced from MacGregor et al. 2010).

Cumulative mortalities of eels passing through a series of hydroelectric facilities on smaller watersheds can also be very high, at times approaching 100% (MacGregor et al. 2010). All the silver eels migrating from Lake Ontario are potentially exposed to the major turbines on the St. Lawrence River and all the eels from the Ottawa River are exposed to the turbines, giving an extent score of very high. The severity score, based on estimates of cumulative mortality at the major dams on the St. Lawrence River is high. Combining the extent and severity scores results in a level of concern which is high for this threat.

4.1.3. Habitat alterations

Silt and sediments

A narrative is provided for this threat because although it scored low on the level of concern, there is a large amount of uncertainty on the impact of this threat on eels in Ontario. Portions of the remaining accessible habitat may be degraded due to poor land use practices, particularly timber harvest, farming practices and urbanization of watersheds that impair stream quality and riparian zones, imposing additional potential stressors to yellow eels (Machut et al. 2007). Clearing and working land to the shoreline, with no buffer strips in particular, can result in erosion and sedimentation of watercourses, leading to infilling of interstitial spaces important to eels as habitat. Sediments arising from such practices also contain contaminants, making eel flesh less safe to eat and posing risks to reproductive success (from MacGregor et al. 2010). That said, current human population growth patterns indicate that quality habitat remains available in Lake Ontario (Pratt and Threader 2011).

4.1.4. Changes in ecosystems

Stocking of native fish

This activity is considered to have a low level of concern but is described here because of its specificity to the situation in Ontario.

A conservation stocking program was undertaken in Ontario during 2006 to 2010 (Pratt and Mathers 2011; Pratt and Threader 2011) with the goal of augmenting American Eel abundance in the productive rearing habitats where naturally recruiting eel abundances were low. The glass eels which were stocked originated from the fisheries in the Bay of Fundy region of New Brunswick and Nova Scotia (Pratt and Threader 2011). If there are indeed genetically based differences in sex ratio and growth between *A. rostrata* of distinct origins, this could imply that stocking of areas where only females are found (such as the upper St Lawrence River system) with glass eels from areas with variable proportions of males may reduce the proportion of females produced in waters being stocked. Also, if slower growing anguillid eels tend to migrate farther upstream in order to avoid competition with faster-growing individuals as proposed by Edeline et al. (2007), such stocking practice could potentially be detrimental for the remnant local anguillid eel stock. Furthermore if there is an association between individual growth characteristics and habitat preference (e.g. downstream v. upstream) as proposed by Edeline (2007) and Edeline et al. (2007) anguillid eels from downstream locations stocked at upper locations may have a reduced fitness and hence may not contribute significantly to spawning escapement (from Cote et al. 2009). Studies to address some of these uncertainties are ongoing.

In addition, it is believed that the recent detection of the swim bladder parasite in a small proportion of sampled eels from Lake Ontario originated from glass eels which were transferred from the Atlantic coast of Canada as source for the conservation stocking program. This threat is identified in the Parasites and Diseases category and the level of concern at this time was assessed as low.

*Table 4.1. Summary of threats to, and rating of effects on, recovery and/or persistence of American Eel in **Ontario.***

Threat	**Specific Threat**	**Level of Concern**	**Extent**	**Occurrence and Frequency**	**Severity**	**Causal Certainty**		**Rationale**
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Directed fishing for American Eel	Commercial fishery in Ontario waters	Low	Low	Historic seasonal	Low	High	High	Commercial fishery for eel (yellow life stage) in Ontario water was closed in 2004 (MacGregor et al. 2010). Data from Zhu et al. (in prep.) indicate that historic fishing levels were partly to blame for the rapid decline in Lake Ontario.
	Commercial fishery in Quebec waters of the St. Lawrence River for silver eels migrating from Ontario	**High**	Very high	Current seasonal	Medium	High	Very High	See text narrative
	Aboriginal fishery	Low	Low	Current seasonal	Negligible	Low	Low	Aboriginal peoples have a long association with the species and have harvested eels for millennia, as exemplified by archaeological evidence from Morrison and Allumette Islands in the Ottawa River (referenced in MacGregor et al. 2010). There is no known current Aboriginal harvest in Ontario.
	Recreational fishery	Low	Low	Historic seasonal	Low	Low	Low	Small recreational fishery in Ontario was closed in 2005 (MacGregor et al. 2010).

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
	Illegal fishing	Low	Low	Current	Low	High	Low	The unreported eel catch was historically believed to be less than 5% in Lake Ontario and 8% in the St. Lawrence estuarine fishery (ICES 2001). These rates are likely lower (or zero in Lake Ontario) given the fisheries closures (Ontario) and fisheries effort reductions (Québec) (COSEWIC 2012).
Bycatch in Other Fisheries	Commercial fishery	Low	Low	Current seasonal	Negligible	Low	Low	Based on daily catch reports of Ontario Ministry of Natural Resources. Current fishery is a live capture entrapment fishery, so minimal by-catch mortality is anticipated. Retention of eel bycatch is prohibited.
	Aboriginal fishery	Low	Low	Current seasonal	Negligible	Low	Low	Based on information provided by Aboriginal communities
	Recreational fishery	Low	Low	Current seasonal	Negligible	Low	Low	Creel surveys show very low catches of eel. Retention is prohibited.
	Illegal fishing	Low	Low	Current seasonal	Negligible	Low	Low	Enforcement staff observations in fish markets. Where eels have been sampled, they originate from outside Ontario.
Directed fisheries on Potential Prey Species of American Eel	Fisheries on prey species of eel	Low	Low	Current seasonal	Negligible	Low	Low	Eels are very plastic in their diet and only eat smaller prey that are not the target of any directed fisheries.
Physical	Loss of habitat - dams and other obstructions to upstream migration	**High**	High	Current seasonal	High	High	High	See narrative text

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
obstructions	Habitat fragmentation due to stream crossing infrastructure (roads / culverts)	**Medium**	High	Current continuous	Low	High	High	See narrative text
	Mortality from turbines at hydro dams during downstream migration	**High**	Very High	Current seasonal	High	Very High	Very High	See narrative text
	Hydrokinetic devices	Low	Low	Anticipatory	Negligible	Very Low	Very Low	Potential exists for these developments
Water quantity	Water extraction (nuclear, thermal, municipal water, irrigation)	Low	Low	Current seasonal	Low	Low	Low	Reports of entrainment and mortality during water taking for nuclear electric generation plants, drinking water intakes, etc. however no quantification of severity
	Water regulation (storage dams, hydro peaking)	Low	Low	Current seasonal	Low	Low	Low	Most large dams are run of the river
	Water level variations associated with climate	Low	Low	Historic, Current seasonal	Low	Low	Low	Some evidence of annual variations in water levels but no information of effects on eels
Water quality	Acidification, eutrophication, anoxic events	Low	Low	Current seasonal	Low	Low	Low	Acidification not an issue. Eutrophication consequences not assessed.
Pollutants, chemicals and wastewater	Toxic chemicals (agriculture, lamprey control programs, industry)	Low	Low	Current seasonal	Low	High	Medium	No documented toxic chemical kills of eels. Lampricides have no effects on eels at operational concentrations
	Heavy metals	Low	Low	Current continuous	Low	Medium	Low	Heavy industry present, eels from lake Ontario and upper St. Lawrence have heavy metal burdens
	Contaminants	Low	Low	Current continuous	Low	Medium	Medium	A threat assessment of various contaminants in Lake Ontario eels has determined current body burdens to be low and likely not a risk to recruitment (Byer et al. 2013a, 2013b)

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Habitat alteration	Silt and sediment (urbanization, agriculture, forestry, mining,)	Low	Low	Current continuous	Low	Medium	Medium	See narrative text.
	Aquaculture effects on habitat	Low	Low	Not applicable	Negligible	Low	Low	No commercial operations that would affect potential habitats of eels.
Parasites and Diseases	Swim bladder nematode *Anguillicoloides crassus*	Low	Low	Current continuous Anticipatory	Low	Low	Low	Experience in LO uSLR suggests that new techniques are needed to detect diseases and parasites in glass eels being screened for stocking programs. Recent detection of *Anguillicoloides crassus* in Lake Ontario, prevalence is low (<2%).
Changes in ecosystems	Changes in prey communities	Low	Low	Current continuous	Negligible	low	Low	No evidence of impoverished species diversity, leading to simplified food web linkages. Recovery of Lake Ontario post 1970.
	Changes in predator communities	Low	Low	Current seasonal	Low	Low	Low	Increased abundance of double crested cormorants in LO uSLR, however, at no time since the studies of cormorant pellets started in 1999 have eel contributed more than 0.1 % of the diet by number (J. Johnson, USGS, pers com. 2013)
Changes in ecosystems	Stocking of native fish (eels)	Low	Medium	Current continuous	Low	Medium	Medium	See narrative text Program only occurs in Lake Ontario
	Aquaculture for eels	Low	Low	Anticipated	Low	Medium	Negligible	No aquaculture of eels currently in this unit. Elsewhere aquaculture has been linked to transmission of *Anguillicoloides crassus* (Kennedy 2007)

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
	Non-native species introductions and establishment	Medium	High	Current continuous	Low	Low	Low	The invasion of dreissenid mussels (e.g., Zebra Mussel; *Dreissena polymorpha*) may also have had some impact on eels in some waters (e.g., Lake Ontario), by increasing water clarity and forcing eels into deeper and thermally less preferred waters (J. Casselman, unpub. Data, cited in MacGregor et al. 2010).
Boat and ship traffic	Mortality and injury from boat / propeller strikes, response to sound, response to movement	Low	Low	Current seasonal	Low	Low	Negligible	Not examined in American Eel. Burrowing behavior would minimize impacts during the day
Underwater electric cables	Effects on migration and orientation	Low	Low	Current continuous	Low	Low	Negligible	No specific information.
Oil and gas exploration	Effects on migration and orientation	Low	Low	Current continuous	Low	Low	Negligible	No specific information.
	Direct mortality	Low	Low	Current continuous	Low	Low	Negligible	No specific information.
Scientific Research	Monitoring, Assessments, Collections, and other Research	Low	Low	Historic recurrent	Low	Low	Low	Electrofishing is a standard sampling technique for eels. Reynolds and Holliman (2004) found increased rates of spinal injury and hemorrhages in eels caught by electrofishing. Other studies on smaller eels have not shown the same results (Pratt and Threader 2011). A limited number of eels are sampled in these programs.

4.2. QUEBEC

The main potential threats to American Eel within Quebec are from the directed commercial fishery, and from physical obstructions (loss of habitat and turbine mortality). Habitat alterations threat although scored as low is also discussed due to the nature of changes occurring ginthe St. Lawrencre River (Table 4.2).

4.2.1. Directed Commercial Fisheries

A description of fisheries management and fisheries gears used in the Quebec commercial fisheries until 1997 is given by Tremblay (1997).

Commercial fisheries are operated in the St. Lawrence River and Estuary and landings are experiencing a decline in both locations. Exploitation rates for silver-phase American Eel by commercial fishing in the lower St. Lawrence River gears was estimated at 21.5% in 1996-1997 (Caron et al. 2003). In 2009, a buyout program was launched in the estuary and of the 67 license holders registered in 2008, 46 (69%) agreed to sell their fishing rights and withdraw from the eel fishery (DFO 2010d). In the Lac St. Pierre fishery, only 6 commercial hoopnet licences remain (DFO 2010d). Only 52 fishing traps are now and effective fishing effort decreased by 48% in 2009 compared to 2008.

The number of silver eels migrating in the St. Lawrence Estuary and the number caught by the remaining fishermen was estimated during two consecutive seasons using mark-recapture experiments in 2010 and 2011. The estimated exploitation rate was 10.7% in 2010 and 7.8% in 2011, with differences due to environmental conditions because fishing effort remained the same both years. Because there is no other anthropogenic mortality downstream, annual net escapement from the freshwater section of the St. Lawrence River to the oceanic spawning grounds was estimated at approximately 140,000 large female silver eels. With exploitation rates averaging 9.2% for both years, the buyout program had a very significant impact on the fishery. It is now less than half of what it was in late 1990's (Caron et al. 2003) and fully met the initial objectives of the draft management plan (DFO 2010d). This decrease in fishing mortality has also an impact on escapement by adding 16,000 to 21,000 spawners to global annual escapement, fish which would otherwise have been harvested if the fishing effort reductions had not been in place.

The extent of this threat is assessed as medium and the severity is assessed as medium which gives a level of concern score of medium.

4.2.2. Physical Obstructions

Loss of habitat

Physical obstructions resulted from dam implementation throughout the historical distribution range. Verreault et al. (2004) estimated that these obstacles prevented free access to 12,140 km^2 of freshwater habitat suitable for eel growth. The loss of free access to growth habitat above dams represents a loss of potential annual escapement estimated at 1,057,394 kg/ year, or 836,545 large female silver eels. Given the long history of upstream passage with various facilities, and the immediate observable success (Solomon and Beach 2004), providing upstream passage above dams is probably the most effective way to restore eel abundance.

Eel ladders are already installed on Beauharnois hydrodam in the upper St. Lawrence-Lake Ontario subwatershed and the same equipment is also found on two dams in the Richelieu River subwatershed. These mitigation measures give access to two of the three largest subwatersheds for eel production in the historic distribution range. The third one is the Ottawa

River and this subwatershed encompasses 3,700 km² of eel habitat. Twelve hydrodams are located on this river itself and six on connected tributaries (Couillard et al. 1992; Haxton and Chubbuck 2002). None of these are equipped with eel ladders and re-opening access could potentially generate nearly 255,000 female silver eels per year.

Mortality from turbines

Mortality rate of silvering eels migrating from upper St. Lawrence River passing the Beauharnois facilities was estimated at 17.8% (Verreault and Dumont 2003). For other existing hydrodams, there are no mortality estimates. Since 1994, provision of both upstream and downstream passage is mandatory for new hydroelectric facilities where American Eel is present.

4.2.3. Habitat alterations

Habitat alterations are widely observed throughout the St. Lawrence watershed and wetlands occupy at least a total area of 33,600 hectares between Cornwall and Trois-Pistoles, excluding aquatic plant communities (Létourneau et Jean 2006). Much of the inhabited shores of Quebec have been altered and developed, natural aquatic habitats have been destroyed or altered for infrastructures or farming purposes. For the St. Lawrence River, 60% of the shoreline has been altered. Some regions, such as Lac Saint-Pierre and other islands are much less altered, while others, particularly in the Montreal area, are up to 90% urbanized. The impact of these alterations on eel productivity is not known.

Table 4.2. Summary of threats to, and rating of effects on, recovery and/or persistence of American Eel in ***Quebec****.*

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Directed fishing for American Eel	Commercial fishery	**Medium**	Medium	Current seasonal	Medium	High	High	See narrative text
	Aboriginal fishery	Low	Low	Historic seasonal	Low	Low	Low	No aboriginal fishery
	Recreational fishery	Low	Low	Historic seasonal	Low	High	Low	No recreational fishery
	Illegal fishing	Low	Low	Historic seasonal	Low	Low	Low	
Bycatch in Other Fisheries	Commercial fishery	Low	Low	Historic seasonal Current	Low	Low	Low	
	Aboriginal fishery	Low	Low	Historic seasonal	Low	Low	Low	
	Recreational fishery	Low	Low	Current seasonal	Low	Low	Low	
	Illegal fishing	Low	Low	Current seasonal	Low	Low	Low	
Directed fisheries on Potential Prey Species of American Eel	Fisheries on prey species of eel	Low	Low	Current seasonal	Low	Low	Low	
Physical obstructions	Loss of habitat - dams and other obstructions to upstream migration	**High**	High	Current seasonal	High	High	High	See narrative text
	Habitat fragmentation due to stream crossing infrastructure (roads /	**Medium**	High	Current seasonal	Low	High	High	See narrative text

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
	culverts)							
	Mortality from turbines at hydro dams during downstream migration	**Medium**	Medium	Current seasonal	Medium	Very High	High	See narrative text
	Hydrokinetic devices	Low	Low	Anticipatory	Negligible	Very Low	Very Low	Proposed pilot projects in the St. Lawrence River
Water quantity	Water extraction (nuclear, thermal, municipal water, irrigation, drawdown)	Low	Low	Current seasonal	Low	Low	Low	
	Water regulation (storage dams, hydro peaking)	Low	Low	Current seasonal	Low	Low	Low	Most large dams are run of the river
	Water level variations associated with climate	Low	Low	Historic, Current seasonal	Low	Low	Low	Some evidence of annual variations in water levels and associations with timing of fishery catches
Water quality	Acidification, eutrophication, anoxic events	Low	Low	Current seasonal	Low	Low	Low	
Pollutants, chemicals and wastewater	Toxic chemicals (agriculture, lamprey control programs, industry)	Low	Medium	Current seasonal	Low	High	Low	
	Heavy metals	Low	Low	Current seasonal	Low	Medium	Low	
	Contaminants	Low	Low	Current seasonal	Low	Medium	Low	

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Habitat alteration	Silt and sediment (urbanization, agriculture, forestry, mining,)	Low	Medium	Current	Low	Medium	Low	See narrative text
	Aquaculture effects on habitat	Low	Low	Current	Low	Low	Low	
Parasites and Diseases	Swim bladder nematode *Anguillicoloides crassus*	Low	Low	Current Anticipatory	Low	Low	Low	
Changes in ecosystems	Changes in prey communities	Low	Low	Current	Low	Low	Low	
	Changes in predator communities	Low	Low	Current	Low	Low	Low	
	Stocking of native fish (eels)	Low	Low	Current	Low	Medium	Low	See narrative text, main section
	Aquaculture for eels	Low	Low	Current	Low	Medium	Low	
	Non-native species introductions and establishment	Low	Low	Current	Low	Low	Low	
Boat and ship traffic	Mortality and injury from boat / propeller strikes, response to sound, response to movement	Low	Low	Current	Low	Low	Low	
Underwater electric cables	Effects on migration and orientation	Low	Low	Current	Low	Low	Low	
Oil and gas exploration	Effects on migration and orientation	Low	Low	Current continuous	Low	Low	Negligible	No specific information.
	Direct mortality	Low	Low	Current continuous	Low	Low	Negligible	No specific information.
Scientific Research	Monitoring, Assessments, Collections, and other Research	Low	Low	Current	Low	Low	Low	

4.3. NEWFOUNDLAND AND LABRADOR REGION

The three main potential threats to American Eel within the Newfoundland and Labrador region are directed removals via fisheries, physical obstructions and habitat alterations (Table 4.3; Veinott and Clarke 2011).

4.3.1. Fisheries

Although the level of concern for this threat scores low, it is discussed here as directed commercial, recreational and aboriginal fisheries are the only recorded source of mortality of eels in insular Newfoundland. An overview of the history of the eel fisheries in Newfoundland and Labrador is given in Knight (1997).

The majority of the directed fisheries target silver eels but fisheries targeting the yellow and elver life stages do occur (Veinott and Clarke 2011; Cairns et al. 2012b). There are management measures in place to reduce the overall effect of these fisheries on the abundance of eel. These measures include a zone along the south coast of the island from Port aux Basques to the Burin Peninsula where no commercial harvesting is allowed and the reduction of licences through retirement, as no new licences are currently being issued.

Large portions of the island of Newfoundland and Labrador are not fished (Cairns et al. 2012b). A total of 86 fishing locations were identified around insular Newfoundland and the percentage of the coastal areas within 1 km and 5 km of fishing locations was estimated at 0.0% and 0.2%, respectively, representing an extent score of low. The value reported in Cairns et al. (2012b) is considered an underestimate. Nicholls (2011) shows many more historical (recent) fishing locations (most of these licences still remain) including on the east coast of the Avalon Peninsula (Renews area) and on the Northeast coast which in Cairns et al. (2012b) is shown as devoid of fishing while it is one of the main areas of fishing in Nicholls (2011). Nicholls (2011) used the log books of actual fishermen to identify fishing activity.

There are no estimates of exploitation rates in these fisheries. Using the estimate of the mean harvest rate (kg/km²/yr) from sheltered areas presented in Cairns et al. (2012b), harvest rates were highest in Area K of the southwest coast of Newfoundland (229.7 kg/km²/yr), higher than 50 kg/km²/yr in three other areas and less than 20 kg/km²/yr in all the other areas (Cairns et al. 2012b; table 11). Highest estimated harvest rates from sheltered coastal areas in eastern Canada were in the range of >200 to < 350 kg/km²/yr putting the highest value from Newfoundland among the highest fished rates. Consequently the severity was scored as medium and the level of concern is scored low.

4.3.2. Physical obstructions

<u>Loss of habitat</u>

A recent review of dams that may affect eel passage was conducted by Nicholls (2011). There are 333 dams on the island that may impact eel passage with 234 being related to hydroelectric infrastructure and another 81 being for water supply. A large number of these dams are related to hydro development on three main river systems: Exploit’s River, Humber River, and Bay d’Espoir area. Water supply systems tended to be situated closer to the coast. While detailed information on historical eel usage or passage is not available for these sites some habitat impacts are expected.

The Newfoundland and Labrador region has a long history of hydroelectric development and many of these sites were developed without the provision of fish passage. Many of the older hydro sites also included extensive water diversions which may have also reduced available habitat (Nicholls 2011). In some cases eels still may migrate into these systems but no information is available about the downstream passage of sliver eels. Even the newer sites have been developed without the provision for the passage of eel. This is an area that requires more study; document potential effects and investigate where passage could be restored.

Habitat fragmentation

Habitat fragmentation can occur either by restricting the movement of elvers upstream or silver eels downstream. The two main potential anthropogenic influences on habitat connectivity are the forest industry through the development of resource roads and hydroelectric development (Table III-3). There are a large number of stream crossings in the region, especially in the island portion, but only perched culverts would provide any difficulty for eel passage and these are becoming rarer. The threat posed by resource road construction should be mitigable with standard best practices.

4.3.3. Habitat alterations

Silt and sediments

The extent of this threat is high within the region due to forestry and extensive road crossing infrastructure. There is little evidence of a reduction in eel production resulting from this threat.

*Table 4.3. Summary of threats to, and rating of effects on, recovery and/or persistence of American Eel for **Newfoundland and Labrador Region**.*

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Directed fishing for American Eel	Commercial fishery	Low	Low	Current seasonal	Medium	High	High	See narrative text
	Aboriginal fishery	Low	Low	Current seasonal	Low	Low	Very Low	No mandatory reporting
	Recreational fishery	Low	Low	Current seasonal	Low	Low	Very Low	No mandatory reporting
	Illegal fishing	Low	Low	Current seasonal	Low	Low	Very Low	
Bycatch in Other Fisheries	Commercial fishery	Low	Low	Current seasonal	Negligible	Low	Low	There is limited evidence that eels are caught as by-catch in any fishery conducted within the Newfoundland and Labrador region. Retention of bycatch is prohibited.
	Aboriginal fishery	Low	Low	Current seasonal	Negligible	Low	Very Low	
	Recreational fishery	Low	Low	Current seasonal	Negligible	Low	Very Low	

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
	Illegal fishing	Low	Low	Current seasonal	Negligible	Low	Very Low	
Directed fisheries on Potential Prey Species of American Eel	Fisheries on prey species of eel	Low	Low	Current seasonal	Negligible	Low	Very Low	
Physical obstructions	Loss of habitat - dams and other obstructions to upstream migration	**Medium**	Medium	Current seasonal	Medium	High	Low	See narrative text
	Habitat fragmentation due to stream crossing infrastructure (roads / culverts)	Low	Medium	Current continuous	Low	High	Low	See narrative text
	Mortality from turbines at hydro dams during downstream migration	Low	Medium	Current seasonal	Low	Very High	Low	The extent to which eels move above hydro dams in Newfoundland is currently unknown, although eels have been observed in the fishways at both Bishop's Fall and Grand Fall's on the Exploit's River so some passage is occurring (Nicholls 2011; K. Clarke personal observation).
	Hydrokinetic devices	Low	Low	Not applicable	Negligible	Very Low	Very Low	No projects proposed

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Water quantity	Water extraction (nuclear, thermal, municipal water, irrigation, drawdowns)	Low	Low	Current continuous	Low	Low	Very Low	The main effect of water extraction would be related to passage issues which has been included in obstructions above.
	Water regulation (storage dams, hydro peaking)	Low	Low	Current seasonal	Low	Low	Low	Across watershed water diversion has occurred. Minimum flow requirements in impacted systems are in place. Hydro-peaking occurs at some facilities but eels likely do not have access to the areas where this occurs.
	Water level variations associated with climate	Low	High	Historic, Current seasonal	Low	Low	Very Low	Important precipitation events observed in all seasons over Newfoundland
Water quality	Acidification, eutrophication, anoxic events	Low	Medium	Current seasonal	Low	Low	Very Low	Acidification of concern in some areas of the island No eutrophication issues in the region
Pollutants, chemicals and wastewater	Toxic chemicals (agriculture, lamprey control programs, industry)	Low	Low	Current seasonal	Negligible	High	Very Low	Some very localized industrial activities
	Heavy metals	Low	Low	Current continuous	Negligible	Medium	Very Low	Some very localized industrial activities
	Contaminants	Low	Low	Current continuous	Negligible	Medium	Very Low	

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Habitat alteration	Silt and sediment (urbanization, agriculture, forestry, mining,)	**Medium**	High	Current continuous	Low	Medium	Low	See narrative text
	Aquaculture effects on habitat	Low	Low	Current continuous	Negligible	Low	Very Low	Limited number of commercial operations (shellfish and finfish) that would affect potential habitats of eels.
Parasites and Diseases	Swim bladder nematode *Anguillicoloides crassus*	Low	Low	Current Anticipated	Negligible	Low	Very Low	No documented cases, but the potential for introduction of parasites and disease always exist.
Changes in ecosystems	Changes in prey communities	Low	Low	Current continuous	Negligible	Low	Very Low	Naturally low fish species diversity, no effect on eels
	Changes in predator communities	Low	Low	Current seasonal	Low	Low	Very Low	
	Stocking of native fish (eels)	Low	Low	Not applicable	Negligible	Medium	Negligible	No eel stocking program currently or anticipated
	Aquaculture for eels	Low	Low	Not applicable	Negligible	Medium	Negligible	No aquaculture of eels in the region
	Non-native species introductions and establishment	Low	Medium Anticipatory	Current continuous Anticipatory	Low	Low	Very Low	Green Crab are known to destroy eelgrass beds which can be used by eel as habitat. Green crab are spreading in the region
Boat and ship traffic	Mortality and injury from boat / propeller strikes, response to sound, response to movement	Low	Low	Current seasonal	Low	Low	Negligible	

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Underwater electric cables	Effects on migration and orientation	Low	Medium	Anticipatory	Low	Low	Negligible	This is a hypothesized potential effect from the transmission cables that are proposed for both the Cabot Strait and the Strait of Belle Isle
Oil and gas exploration	Effects on migration and orientation	Low	Low	Current continuous	Low	Low	Negligible	No specific information.
	Direct mortality	Low	Low	Current continuous	Low	Low	Negligible	No specific information.
Scientific Research	Monitoring, Assessments, Collections, and other Research	Low	Low	Current seasonal	Negligible	Low	Very Low	Electrofishing is a limited sampling technique in the region, targeted sampling program for salmonids. Salmonid counting fences and fishways are operated on a small number of rivers. Number of eels handled annually is low relative to total inferred population size in the region.

4.4. SOUTHERN GULF OF ST. LAWRENCE

In the threats assessment conducted for this review, commercial fisheries, physical obstructions (loss of habitat, and habitat fragmentation), habitat alterations, parasites, and changes in predator communities were assessed at medium or high levels of concern (Table 4.4).

Narrative text is provided for some threats that scored low when sufficient information is required to justify the assessment.

4.4.1. Directed Commercial Fisheries

The commercial fishery is historically and currently an important fishery which occurs throughout the southern Gulf of St. Lawrence tidal and brackish waters (and in a limited number of freshwater areas), in all seasons (Eales 1968; Paulin 1997; Chaput et al. 1997; Cairns 2005). Various gears are permitted in the commercial fishery including fishing lines, eel pots, dip nets, longlines, set lines, eel traps and spears. A traditional fishery called flambau involved fishing at night with spears and lights (historically torches).

The commercial fisheries target mostly yellow eels and the harvests are presently regulated by a minimum size of > 530 mm. Minimum sizes have varied over time (DFO 2010d). Commercial spearing for eels on PEI was closed in 2005 and a requirement to retain all eels was imposed on the winter recreational spear fishery in 2005 in Gulf New Brunswick and in 2007 in Gulf Nova Scotia to prevent high-grading, i.e., the practice of discarding dead, injured, or small eels in order to provide room to catch larger eels within the daily bag limit (DFO 2010d).

A total of 2,858 fishing locations were identified in the tidal and coastal waters of the southern Gulf of St. Lawrence and the percentage of the coastal areas within 1 km and 5 km of fishing locations was estimated at 1.2% and 5.0%, respectively (Cairns et al. 2012b). Formally this equates to an extent score of low, however because of the large number of fishing locations, the large amount of gear fished or potentially fished, the broad distribution of effort in all areas of the southern Gulf, and that fishing occurs in all seasons, the extent was scored as high.

Based on the estimate of the mean harvest rate ($kg/km^2/yr$) from sheltered areas presented in Cairns et al. (2012b), harvest rates are high in all areas of PEI (5 of 6 counties with harvest rates between 103 and 326 $kg/km^2/yr$) and New Brunswick (4 of 5 counties with harvest rates between 171 and 338 $kg/km^2/yr$). Annual exploitation rates, which may be upwardly biased, based on the total harvests as a percent of the estimated standing stock of eels > 35 cm (minimum size limit at the time of the assessment) are estimated to be 29.7%, 6.7%, and 5.3% in Gulf NB, Gulf NS, and PEI, respectively (D. Cairns, DFO, pers. comm.). As these fisheries are primarily yellow eel fisheries, these exploitation rates would apply over several years while yellow eels remain in the area and are within the size range for retention. As a result, severity is scored as medium.

The combined extent and severity scores results in a level of concern scored medium.

4.4.2. Physical Obstructions

Loss of habitat

Although this threat would be assessed as low on the level of concern, it is given a level of concern score of medium due to the area extent of the barriers in the region and the impact these may have to restrict the unimpeded movements of eels between freshwater and brackish water areas, a phenomenon which is ubiquitous in eels in this region (Lamson et al. 2006; Cairns et al. 2009).

There is only one commercial hydro-electric facility in the region (on the Nepisiguit River in northeast NB), located at a waterfall which was impassable to salmonids. A fyke netting campaign above the dam caught only a single eel, suggesting that the dam (or natural waterfall) blocks most upstream migration (Walker 2012). There are many low dams in the region, including 800 in PEI (MacFarlane 1999) and none have fish passage that is designed for eels. Nevertheless, eels are abundant in most PEI headponds (Cairns et al. 2007), which reflects the species' ability to ascend low barriers. Low dams may increase rather than decrease total habitat available to eels, as shallow lacustrine habitat created by barriers in these areas are more productive than the small fluvial areas which have been lost.

Several small barriers have been removed in recent years (two in the Miramichi River, a tidal causeway on Eel River) which now provide unimpeded access to habitat.

Habitat fragmentation

In addition to the identified dams, the region has a dense network of public and private (farm, logging) roads with a correspondingly large number of stream crossings. Breau (2013) reported that impediments to fish passage were present in 47% of 669 sites in Gulf NS that had a stream crossing within 1 km of head of tide. Hanging culverts and velocity barriers at stream crossings likely impede access to a substantial portion of freshwater habitat in the region.

The extent of the threat is scored as medium and the severity is scored medium due to the impediments these crossing structures have to eel access to freshwater.

4.4.3. Water quality

This threat is scored as medium because of the frequency and extent of hypoxic events on PEI that appear to be on a rising trend.

Acidification is not considered to be a major issue in the region due to buffering effects.

Sea lamprey are a native anadromous fish in the region, are considered to be an important component of the anadromous species biodiversity, and control of their abundance through fish toxicants is not practiced or even considered in the region.

In Prince Edward Island, eutrophic conditions persist in many estuaries and bays that incise the coastline (Cairns 2002). The most striking symptoms of this are the excessive blooms of sea lettuce (*Ulva* sp.) that eventually die and decompose leading to many sections of bay and estuary habitat on Prince Edward Island commonly becoming hypoxic in summer and early fall (Schein et al. 2011). When these events happen, the water turns whitish, accompanied by strong odors, and shellfish in the area die (Cairns 2002). Fish that are unable to relocate also die. Direct mortality to free-living eels is not known, but eels retained in fyke net fisheries located in estuaries when such events happen are frequently found dead in the nets.

4.4.4. Habitat alterations

Silt and sediments

A narrative is provided for this threat. Although it scored low on the level of concern, there is a large amount of uncertainty on the impact of this threat on eels in the region.

Watercourses are subject to widespread alteration due to urbanization, agriculture, forestry, and other human activities. Major effects include siltation, bank stabilization, construction of wharves and other structures adjacent to or in the water, dredging, and infilling of intertidal and shallow subtidal waters for development. Dredging may displace and possibly permanently inter eels resting in daytime burrows. Infilling of salt marshes prevents access by eels, but salt marshes appear to be little used by eels in the region (Cairns et al. 2007). In general, activities which alter, rather than destroy, aquatic habitat probably have little impact on eels because of the plastic nature of the habitat use by eels.

Siltation of streams, rivers, ponds, estuaries and bays is widespread and is especially intense in PEI (Cairns 2002). However, silted bottoms are a readily accepted habitat for eels, and are preferred over sand and gravel bottoms (Tomie et al. 2013).

4.4.5. Parasites and diseases

Swim bladder nematode – *Anguillicola crassus*

Much of the specific information concerning the pathological effects of the parasite is based upon investigations of infected European eels, including: capillary hemorrhages, bloody fluid and dead tissue of nematodes within the swim bladder, parasitic nodules in the swim bladder, enlarged pneumatic ducts, and thickened swim bladder wall. These 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.

In 2005-2007, the nematode *Anguillicoloides crassus* was detected in 8 of 26 (30.1%) eels sampled in Margaree Harbour, NS, and in 0 of 146 eels sampled in Malpeque Bay, PEI (Aieta and Oliveria 2009). In 2008-2009, *A. crassus* was found in 0 of 40 eels in the Miramichi River, NB, 0 of 5 eels in Baileys Brook, NS, 2 of 2 eels in West River, NS, and 3 of 11 (27.3%) in Mill Brook, NS. Prevalence was 46% in 2009-2010 in the Bras d'Or Lakes, just east of the region (Denny et al. 2013).

Based on recent history and the presence of the parasite in Nova Scotia waters of the southern Gulf of St. Lawrence, *A crassus* is likely to increase its distribution overall in the Southern Gulf.

4.4.6. Changes in ecosystems

Non-native species introductions and establishment

Smallmouth bass have become established in several rivers in Gulf Nova Scotia and in a headwater lake of the Miramichi River, New Brunswick (DFO 2009a). Smallmouth bass might be a potential eel competitor in freshwater habitats.

The invasive European green crab arrived in the eastern part of the southern Gulf in the 1990s, and has since spread westward (Klassen and Locke 2007). Invasive green crabs commonly cause major habitat changes, including the destruction of eelgrass beds (Malyshev and Quijon 2011). Green crabs may interfere with eel fisheries by filling and damaging nets, but the impact on eel populations are unclear. Green crabs have invaded the east and central part of the region and are expanding to the west.

Table 4.4. Summary of threats to, and rating of effects on, recovery and/or persistence of American Eel in the ***southern Gulf of St. Lawrence****.*

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Directed fishing for American Eel	Commercial fishery	**Medium**	Medium	Current seasonal	Medium	High	Very High	See narrative text
	Aboriginal fishery	Low	Low	Current seasonal	Negligible	Low	Low	Eels were commonly fished by aboriginal peoples in the Maritime region in historic and prehistoric times (Chute 1998, Denny et al. 2012). Current fishing effort is low or nil.
	Recreational fishery	Low	Low	Current seasonal	Negligible	Low	Low	Eels are speared recreationally through winter ice. Landings are poorly known but are probably small.
	Illegal fishing	Low	Medium	Current seasonal	Negligible	Low	Low	According to anecdotal reports from fishery officers, illegal fishing is probably very small.
Bycatch in Other Fisheries	Commercial fishery	Low	Medium	Current seasonal	Negligible	Low	Low	Minimal. Some eels may be taken in enclosing gear such as smelt and silverside traps, but these eels are probably released alive. Retention of bycatch of eels is prohibited.
	Aboriginal fishery	Low	Medium	Current seasonal	Negligible	Low	Low	Minimal
	Recreational fishery	Low	Low	Current seasonal	Negligible	Low	Low	Eels are occasionally caught by anglers.
	Illegal fishing	Low	Medium	Current seasonal	Negligible	Low	Low	Minimal
Directed fisheries on Potential Prey Species of American Eel	Fisheries on prey species of eel	Low	Medium	Current seasonal	Low	Low	Low	Eel diet includes silversides, smelts, and winter flounder which are commercially fished in the region. However eels are very plastic in their diet.

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Physical obstructions	Loss of habitat - dams and other obstructions to upstream migration	**Medium**	Medium	Current seasonal	Low	High	Low	See narrative text
	Habitat fragmentation due to stream crossing infrastructure (roads / culverts)	**Medium**	Medium	Current continuous	Medium	Medium	low	See narrative text
	Mortality from turbines at hydro dams during downstream migration	Low	Low	Current seasonal	Negligible	Very High	Very low	There is only one commercial hydro-electric dam in the region (on the Nepisiguit River in NE NB) and it is located at a natural falls with very few eels above.
	Hydrokinetic devices	Low	Low	Not applicable	Negligible	Very Low	Very Low	No projects proposed
Water quantity	Water extraction (nuclear, thermal, municipal water, irrigation)	Low	Low	Current seasonal	Low	Low	Low	Water extraction for the City of Charlottetown has depleted water in branches of the nearby Winter River. Some municipal water supply infrastructures have dewatered streams. A 490 MW coal-fired generating station is located in Belledune, on the NB coast of the Bay of Chaleur. This area has an exposure classification of Exposed Bay (Cairns et al. 2012b), which means that resident eels are likely to be rare or absent. There are other thermal generating stations in the region, but they generally operate only as back-ups or for peak periods.

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
	Water regulation (storage dams, hydro peaking)	Low	Low	Current seasonal	Low	Low	Low	Only one commercial hydro-electric dam in the region (on the Nepisiguit River in NE NB) and it is essentially a run of the river facility
	Water level variations associated with climate	Low	Low	Historic, Current seasonal	Low	Low	Very Low	No evidence that natural variations in water levels are affecting freshwater and diadromous fish populations
Water quality	Acidification, eutrophication, anoxic events	Low	Low	Current seasonal	Low	Low	Low	See narrative text
Pollutants, chemicals and wastewater	Toxic chemicals (agriculture, lamprey control programs, industry)	Low	Low	Current seasonal	Low	High	Low	Fish kills caused by agricultural chemicals occur periodically on PEI. Literature reports (e.g. Cairns et al. 2010, 2012a) emphasize mortality to salmonids, but eels are probably killed as well.
	Heavy metals	Low	Low	Current continuous	Low	Medium	Low	Some heavy industry present in the region. Three pulp and paper mills have been closed and decommissioned in past five years.
	Contaminants	Low	Low	Current continuous	Low	Medium	Low	Concentrations of lipophilic organic contaminant (PCBs, OCPs, PBDEs) in eels from the Miramichi and Margaree Rivers were generally lower than those measured elsewhere in northeastern North America, although some Miramichi loads exceeded guidelines for fish health (Byer et al. 2013b).

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Habitat alteration	Silt and sediment (urbanization, agriculture, forestry, mining,)	**Medium**	High	Current continuous	Low	Medium	Low	See narrative text.
	Aquaculture effects on habitat	Low	Low	Current continuous	Low	Low	Low	Blue mussel and oyster aquaculture is widely practiced in the region, especially on PEI. Anecdotal reports from divers indicate that small eels commonly inhabit mussel clumps that are suspended from longlines.
Parasites and Diseases	Swim bladder nematode *Anguillicoloides crassus*	**Medium**	High	Current continuous Anticipatory	Medium	Low	Low	See narrative text
Changes in ecosystems	Changes in prey communities	Low	Low	Current continuous	Negligible	Low	Low	Natural freshwater fish species diversity is low in the region, especially in PEI (Curry 2007). The large number of crossing infrastructures may possibly further depress fish diversity. This could harm eels by removing potential prey, but it could also benefit eels by removing potential competitors and predators.
	Changes in predator communities	Medium	High	Current seasonal	Low	Low	Very Low	A review of avian piscivore diet studies in the Maritime Provinces indicate that eels were 3.5% of double-crested cormorants diets, 1.6% of great cormorant diets, 4.5% of common merganser diets, and 1.0% of belted kingfisher diets (Cairns 1998). Cairns and Kerekes (2000) estimated that common loons and common mergansers consumed between 54 and 100% of fish production in the Kejimkujik Lakes, Scotia-Fundy region.

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
	Stocking of native fish (eels)	Low	Low	Current continuous	Low	Medium	Very Low	No stocking of eels in the region. Stocking of Atlantic salmon, brook trout, and rainbow trout occurs in some areas but is unlikely to have widespread impact on biological communities.
	Aquaculture for eels	Low	Low	Current continuous	Negligible	Medium	Very Low	An eel handling and processing operation in Port Elgin, NB, may hold and feed eels for extended periods. However effects on wild populations are likely nil because the facility uses only well water and has no water connection to any watercourse.
	Non-native species introductions and establishment	Low	Medium (anticipatory)	Current continuous Anticipatory	Low	Low	Very Low	See narrative text. Also Didymo has been observed in the Restigouche River and this organism may affect fluvial habitat characteristics in small areas of the river.
Boat and ship traffic	Mortality and injury from boat / propeller strikes, response to sound, response to movement	Low	Low	Current seasonal	Negligible	Low	Low	The region is not a major shipping lane. Local shipping traffic (cruise ships, bulk carriers for gravel, coal, oil, potatoes, etc.), are unlikely to affect eels. Proposed petroleum exploration between the Magdalen Islands and the southwest coast of Newfoundland could possibly lead to spills that affect the region.
Underwater electric cables	Effects on migration and orientation	Low	Low	Current continuous Anticipatory	Negligible	Low	Negligible	Underwater transmission cable between NB and PEI has operated for decades. Effects on eels not studied. Proposed transmission link across Cabot Strait.
Oil and gas	Effects on migration and orientation	Low	Low	Current continuous	Low	Low	Negligible	No specific information.

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
exploration	Direct mortality	Low	Low	Current continuous	Low	Low	Negligible	No specific information.
Scientific Research	Monitoring, Assessments, Collections, and other Research	Low	Low	Historic Current Seasonal	Negligible	Low	Very Low	Electrofishing is a standard sampling technique in freshwater monitoring programs directed at salmonids. Eels are an occasional bycatch. Eels handled in rotary screw trap programs and occasionally captured in estuarine trapnet programs. Except for dedicated collections, eels are released alive. Limited numbers of eels are sampled in these programs.

4.5. ATLANTIC COAST OF NOVA SCOTIA AND BAY OF FUNDY

In the threats assessment conducted for this review, commercial fisheries (large eel, elvers), physical obstructions (loss of habitat, habitat fragmentation, turbine mortality), water quality (acidification), habitat alterations, parasites, and changes in freshwater ecosystems were assessed at medium or high levels of concern (Table 4.5).

4.5.1. Directed Fisheries

Commercial fishery (large eel)

The commercial fishery for eels is historically and currently an important fishery which occurs throughout the Atlantic coast of Nova Scotia and the Bay of Fundy (Scotia-Fundy), in tidal and freshwaters, in all seasons (Eales 1968; Stevens 1997; Cairns et al. 2012b; Bradford 2013). Authorized fishing methods include angling, pots, traps (fyke nets and weirs), dip nets and spears. Longlines and setlines are permitted in New Brunswick. There is a closed season for eel traps in inland waters from November 1 to August 14 and for spears all year (Stevens 1997; Bradford 2013).

The commercial fisheries target mostly yellow eels and the harvests are presently regulated by a minimum size of limit for eels of 35 cm since 2005 and escape mechanisms with 1 inch by ½ inch openings are mandatory for all gear under licence for fishing large eels and as well within containers left in water bodies to hold eels from the time they are captured until they are sold (Bradford 2013).

A total of 151 fishing locations were identified in the tidal and coastal waters of Scotia-Fundy and the percentage of the coastal areas within 1 km and 5 km of fishing locations was estimated at 0.1% and 1.2%, respectively (Cairns et al. 2012b). Formally this equates to an extent score of low, however many of the sites are estuarial and located in the marine component of the total habitat available to eels that migrate regularly between fresh and salt water (Jessop et al. 2006). The potential for these localized fisheries to affect overall eel productivity over an extensive area of Scotia-Fundy region is therefore scored as high.

Based on the estimate of the mean harvest rate (kg/km²/yr) from sheltered areas presented in Cairns et al. (2012b), harvest rates are generally low (< 25 kg/km²/yr in 4 of 21 areas) with the highest values ranging from 35 to 154 kg/km²/yr in the south shore of Nova Scotia and in the Nova Scotia Bay of Fundy areas (Cairns et al. 2012b). There are no estimates of exploitation rates for these fisheries. The increase in landings that occurred between 1985 (80 mt) and 1996 (230 mt), and the decline afterward appear to reflect changes in the number of participants in the fishery more so than change in eel abundance (Bradford 2013). As these fisheries are primarily yellow eel fisheries, exploitation is applied over several years while yellow eels remain in the area and are within the size range of retention. As a result, severity is scored as medium.

Combined extent and severity scores results in a level of concern scored medium.

Commercial fishery (elvers)

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).

Fishing activity is distributed among 82 named rivers/streams. Reported landings of elvers ranged from 100 to 4,100 kg between 1990 to 2007 (Bradford 2013).

Annual exploitation rates in elver dipnet fisheries in a small river in the Atlantic coast of Nova Scotia were estimated to have ranged from 30.8% to 51.8% over three years of assessment (Jessop 2003). More recent estimates are 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. Unpubl. Rep.)

Based on these, the extent of occurrence was scored as medium and the severity was scored as medium which gives a level of concern score of medium. Causal certainty of impacts is ranked low because the extent to which density dependent factors influence elver survival and growth is not known.

4.5.2. Physical Obstructions

Loss of habitat

In the Southern Uplands of Nova Scotia, 279 dams blocked access to 3,008 km of stream length, or 9.3% of available habitat, to salmonids (DFO 2013; Pratt et al. 2014). In the Inner Bay of Fundy, 131 dams blocked access to 1,299 km of streams, or 7.1% of available habitat, to salmonids. Barriers were documented on 13 of 18 medium and large rivers entering the Bay of Fundy in New Brunswick of which 6 rivers contained barriers that apparently permit some fish passage, and 7 prevented fish passage or block water flow (Pratt et al. 2014). Twenty-three percent of the rivers with barriers contained functional fishways or aboiteaux. The extent to which these dams block access to habitat for the American Eel is not known.

The extent of rearing habitat (including headponds) not available to American Eel on the Saint John River, the largest watershed in the Maritimes provinces, because of hydrodams without active passage facilities for eel is 34.5 km^2, representing 53% of the total wetted area (65.2 km^2) that prior to the construction of the hydrodams would have been accessible to eels.

Habitat fragmentation

In addition to the identified dams, the region has a dense network of public and private (farm, logging) roads with a correspondingly large number of stream crossings (DFO 2013). The extent of the threat is scored as medium and the severity is scored medium due to the impediments these crossing structures have to eel access to freshwater. However, the causal certainty is considered to be low.

Mortality from turbines

There are at least 17 hydro systems, 54 generators and as many as 155 dams in Nova Scotia lakes and rivers which are used to generate electricity. One hydro system may contain several generators and many dams to create electricity. An additional eight hydro systems exist on New Brunswick rivers draining to the Bay of Fundy. Not all systems possess downstream bypass facilities. There are few estimates of downstream bypass efficiency and/or turbine mortality available for hydro systems on the region. Carr and Whoriskey (2008) documented use of a bypass facility by 6 of 25 (24%) silver eels and total mortality of the 19 eels that passed through the turbines yielding an overall mortality rate of 76% for the sample population.

4.5.3. Water quality

This threat is scored as medium because the land-base of the region is altered for human use (farms, forestry, towns and cities on waterways etc). Acidification is a major issue in the southern Uplands region of Nova Scotia for salmonids (DFO 2013). Jessop (2003) suggested that anthropogenic acidification of many Nova Scotia rivers, to pH's as low as 4.2, could result in high mortality rates among elvers. However, Reynolds (2011) has recently shown that the American Eel is fully acid tolerant upon migration into fresh water as there was zero mortality among elvers in both natural and artificial acidic environments with pH levels as low as 4.0 (experimental range 4.0 to 7.0). Further, absence of a response in hematocrit and blood plasma osmolarity levels to exposure to pH's ranging from 4.0 to 7.0 indicated that acidification is not likely to impede regulation of blood ion concentration suggesting any sub-lethal effects that might arise from exposure to low pH are not physiological. However, they would be susceptible to aluminum toxicity.

4.5.4. Parasites and diseases

<u>Swim bladder nematode – Anguillicoloides crassus</u>

The swim bladder parasite has been identified from eels in 8 of 61 surveyed rivers in the Provinces of New Brunswick and Nova Scotia (Aieta and Olivera 2009; Campbell et al. 2013) and in the tidal waters of the Bras D'Or Lakes (Denny et al. 2013) and the east coast of Cape Breton Island (Rockwell et al. 2009). *A. crassus* prevalence was 7.9% and 0.7% for freshwater resident eels collected from New Brunswick and Nova Scotia rivers respectively (Campbell et al. 2013) while mean intensity was generally low: 2.3 for all samples combined and 2.6 and 1.5 for NB and NS samples, respectively (Campbell et al. 2013). Significantly, the parasite was present in eels throughout the lower Saint John River drainage, an area which typically contributes one half of the regions reported landings. The parasite was found with high prevalence (42%) in eels sampled from the Bras d'Or Lakes in Cape Breton (Denny et al. 2013). For the Cape Breton area, Denny et al. (2013) suggest that the likely introduction of *A. crassus* was through an intermediate host in ballast water as the sites with the highest prevalence and greatest number of heavily infected eels were within 13 to 20 km of the international shipping ports in the area. Although unconfirmed, Denny et al. (2013) also speculate that mortalities of eels reported by aboriginal fishermen in 2008 and 2009 could be attributed to a combination of infection by the swim bladder parasite which compromised the ability of eels to cope with poor water quality. Based on recent history and experience with the swim bladder parasite in other jurisdictions, and the wide-spread, patchy distribution of the parasite in Nova Scotia and New Brunswick waters, *A crassus* is likely to increase its distribution in the region.

4.5.5. Changes in ecosystems

<u>Changes in prey communities</u>

Wide-spread illegal introductions of Smallmouth Bass (DFO 2009a) and Chain Pickerel in Nova Scotia lakes has resulted in a collapse of freshwater fish species diversity, including littoral minnow-sized species, and near complete loss of all soft-rayed finfish species (Bradford et al. 2004). The diet of lake resident eels in the invaded waterbodies has not been assessed.

Brown Bullhead Catfish abundance, a native fish, has increased significantly in the Saint John River in recent years (R.G. Bradford unpublished data; Kidd et al. 2011), to the extent that they now interfere with the performance of the eel fishery. Neither the ecological causes nor consequences are understood.

None of these changes in prey communities would be beneficial to eels.

Changes in predator communities

In addition to the effects of invasive predator species on prey communities mentioned above, the role of invasive Smallmouth Bass and Chain Pickerel, and of the native Brown Bullhead Catfish when present in high abundance as predators on eels is not known.

*Table 4.5. Summary of threats to, and rating of effects on, recovery and/or persistence of American Eel in the **Atlantic Coast of Nova Scotia and Bay of Fundy**.*

Threat	**Specific Threat**	**Level of Concern**	**Extent**	**Occurrence and Frequency**	**Severity**	**Causal Certainty**		**Rationale**
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Directed fishing for American Eel	Commercial fishery (Large Eel)	**Medium**	Medium	Current seasonal	Medium	High	Very High	See narrative text
	Commercial fishery (Elvers)	**Medium**	Medium	Current Seasonal	Medium	Low	Low	See narrative text
	Aboriginal fishery	Low	Low	Current seasonal	Negligible	Low	Low	Eels are fished by aboriginal peoples for Food, Social and Ceremonial purposes. There are no indications that either catches or effort are high.
	Recreational fishery	Low	Low	Current seasonal	Negligible	Low	Low	Probably occurs
	Illegal fishing	Low*	Low	Current seasonal	Negligible	Low	Low	Minimal – but there conflicting reports of importations into Europe that imply larger harvests of elvers than is reported by DFO
Bycatch in Other Fisheries	Commercial fishery	Low	Medium	Current seasonal	Negligible	Low	Low	Minimal. Most American eels are probably capable of escape from most kinds of fish traps. Eels are not expected to be present in large numbers in locations where hook and line commercial fishing is practiced. By-caught eels cannot be retained by condition of licence.
	Aboriginal fishery	Low	Medium	Current seasonal	Negligible	Low	Low	Minimal
	Recreational fishery	Low	Low	Current seasonal	Negligible	Low	Low	Eels are susceptible to capture by recreational anglers, particularly on baited terminal gear.
	Illegal fishing	Low	Medium	Current seasonal	Negligible	Low	Low	Minimal

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Directed fisheries on Potential Prey Species of American Eel	Fisheries on prey species of eel	Low	Medium	Current seasonal	Low	Low	Low	Eels have a varied diet.
Physical obstructions	Loss of habitat - dams and other obstructions to upstream migration	**Medium**	Medium	Current continuous	Medium	High	High	See narrative text
	Habitat fragmentation due to stream crossing infrastructure (roads / culverts)	**Medium**	High	Current continuous	Low	Medium	Low	See narrative text
	Mortality from turbines at hydro dams during downstream migration	**Medium**	High	Current continuous	Medium	Very High	Medium	See narrative text
	Hydrokinetic devices	Low	Low	Anticipatory	Negligible	Very Low	Very Low	Pilot projects proposed, related to tidal power in Bay of Fundy
Water quantity	Water extraction (nuclear, thermal, municipal water, irrigation)	Low	Low	Current	Low	Low	Low	The adequacy of maintenance flows on the middle portions of the Saint John River has been questioned (Kidd et al. 2011). However, this large section of the river is presently not available to American Eel because they cannot pass over Mactaquac Dam located downstream.

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
	Water regulation (storage dams, hydro peaking)	Low	Low	Current seasonal	Low	Low	Low	Storage dams and water releases for hydropeaking occur in the Saint John River system, primarily above Mactaquac Dam which is not accessible to eels. Suggested that increased flows from turbine operations may hinder upstream migration of elvers.
	Water level variations associated with climate	Low	Low	Historic, Current seasonal	Low	Low	Very Low	No evidence that natural variations in water levels are affecting freshwater and diadromous fish populations
Water quality	Acidification, eutrophication, anoxic events	Low	Low	Current	Low	Low	Low	See narrative text. Considerations for parasites in areas of low water quality (NS)
Pollutants, chemicals and wastewater	Toxic chemicals (agriculture, lamprey control programs, industry)	Low	Low	Current	Low	High	Low	Fish kills associated with agricultural chemicals are not common in this region.
	Heavy metals	Low	Low	Current continuous	Low	Medium	Low	Some heavy industry present in the region.
	Contaminants	Low	Low	Current continuous	Low	Medium	Low	
Habitat alteration	Silt and sediment (urbanization, agriculture, forestry, mining,)	**Medium**	High	Current continuous	Low	Medium	Low	See narrative text, general section.
	Aquaculture effects on habitat	Low	Low	Current continuous	Low	Low	Low	
Parasites and Diseases	Swim bladder nematode *Anguillicoloides crassus*	**Medium**	High (anticipatory)	Current continuous Anticipatory	Low	Low	Low	See narrative text.
Changes in	Changes in prey communities	**Medium**	Medium	Current continuous	Medium	Low	Low	See narrative text

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
ecosystems	Changes in predator communities	**Medium**	High	Current continuous	Medium	Low	Low	See narrative text.
	Stocking of native fish (eels)	Low	Low	Current continuous	Low	Medium	Low	No stocking of eels in the region. Stocking of Atlantic salmon, brook trout, and rainbow trout occurs in some areas but is unlikely to have widespread impact on biological communities.
	Aquaculture for eels	Low	Low	Current continuous	Negligible	Medium	Low	There is one grow out facility in New Brunswick (Pennfield) which is inactive and another in Nova Scotia (Springhill). Both are land-based facilities.
	Non-native species introductions and establishment	**Medium**	High	Current continuous Anticipatory	Medium	Low	Low	See narrative text for Changes in Prey Communities and Changes in Predator Communities Green crab in this category due to presence in tidal waters
Boat and ship traffic	Mortality and injury from boat / propeller strikes, response to sound, response to movement	Low	Low	Current seasonal	Negligible	Low	Low	See narrative text, general section
Underwater electric cables	Effects on migration and orientation	Low	Low	Current continuous Anticipatory	Negligible	Low	Low	See narrative text, general section
Oil and gas exploration	Effects on migration and orientation	Low	Low	Current continuous	Low	Low	Negligible	No specific information.
	Direct mortality	Low	Low	Current continuous	Low	Low	Negligible	No specific information.

Threat	Specific Threat	Level of Concern	Extent	Occurrence and Frequency	Severity	Causal Certainty		Rationale
		Overall for region	% Populations affected	**C**urrent, **H**istoric, **A**nticipated	Current Population impacts	Evidence in general on species	Evidence on specific region	Context for threats assessment
Scientific Research	Monitoring, Assessments, Collections, and other Research	Low	Low	Historic, Current,	Negligible	Low	Very Low	Electrofishing and rotary screw traps are commonly used sampling tools in Maritimes Region rivers/stream and eels are captured with regularity. These are mostly released unharmed. Resumption of systematic assessment of the prevalence and intensity of *A. crassus* in the American Eel (Campbell et al. 2013) could require lethal sampling of several thousand eels.

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