HISTORIC EXAMINATION OF THE CHANGES IN DIADROMOUS FISH POPULATIONS AND POTENTIAL ANTHROPOGENIC STRESSORS IN THE AVON RIVER WATERSHED, NOVA SCOTIA

By

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Abstract

Diadromous fish populations in the Avon River Watershed (ARW), a tidal river system which empties into the Minas Basin, are suspected to have declined from historic abundances, especially since the construction of the Windsor Causeway in 1970. Historic and contemporary scientific and qualitative information was integrated to develop an understanding of the historic status of and changes in ARW diadromous populations from European settlement to the present and to explore the potential causal relationships with human-imposed stressors. Data sources included: interviews with local knowledge holders and experts; written historical and contemporary records; catch statistics; existing fish surveys; and museum specimens. This study was undertaken to provide information for fish and watershed conservation/restoration planning.

The findings confirm that the ARW historically supported populations of anadromous Atlantic salmon, alewife, blueback herring, rainbow smelt, and sea-run brook trout, and catadromous American eel. There is also some inconclusive evidence that there may have been a historic American shad population. Anadromous population declines had been noted since the mid-19th century. A brief recovery period was experienced in the late 19th to early 20th centuries, followed by a marked declining trend throughout the mid to late 20th century. Sources conflict regarding the extent of declines prior to the Windsor Causeway's construction. Government documents from the 1960s reported that anadromous populations had decreased to low abundances by the mid-1960s; whereas local sources asserted that fair-sized populations persisted until the 1970s. Nonetheless, sources agree that major declines began to manifest in the early 1970s. Shad has not been reported in the ARW since 1970. There has been no evidence of salmon since the late 1980s, which suggests the probable extirpation of this population. The remaining anadromous populations persist at well below their historic abundances. Eels are still present, though changes in abundance over time could not be ascertained. The findings indicate that hydro power operations and the Windsor Causeway have been the most prominent 20th century stressors on diadromous populations, with the causeway having been a primary contributor to the declines experienced since its construction. Other major historic and contemporary stressors have been identified as: mill-dams; saw-dust and other mill pollution; over-exploitation; removal/thinning of riparian zones; and nutrient, pesticide, sewage and industrial pollution discharges.

Based on the results of this historical review, several recommendations were made to guide conservation/restoration planning including: developing an ecosystem-based watershed management strategy; mitigating/eliminating fish passage restrictions through the causeway; mitigating hydrological fluctuations caused by hydro power operations; and continued research and monitoring of fish populations, habitat, and the impacts of stressors.

List of Abbreviations

ARW: Avon River Watershed

BoF: Bay of Fundy

COSEWIC: Committee on the Status of Endangered Wildlife in Canada

DFO: Department of Fisheries and Oceans

DMF: Department of Marine and Fisheries

EIA: Environmental Impact Assessment

iBoF: inner Bay of Fundy

KI: Key Informant

MMRA: Maritime Marshland Rehabilitation Administration

NBDSS: New Brunswick Department of Supply and Service

NSDAF: Nova Scotia Department of Agriculture and Fisheries

NSDAM: Nova Scotia Department of Agriculture and Marketing

NSDNR: Nova Scotia Department of Natural Resources

YOY: Young-of-the-year

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Chapter 1: Introduction

Since European settlement in the 17th century, human activities have been impacting diadromous[1] fish populations and other aquatic biota in the tidal river systems throughout the Bay of Fundy (BoF) region. Diadromous fish play critical ecological roles in freshwater, estuary and marine environments (Willson and Halupka, 1995; Bilby *et al*., 1996). Thus, the deterioration or loss of individual populations or entire species may have detrimental effects on the ecological integrity of overall watersheds and possibly the whole BoF. Historically, most of the major BoF tidal river watersheds supported abundant diadromous populations; the anadromous Atlantic salmon (*Salmo salar*), rainbow smelt (*Osmerus mordax*), and gaspereau (a term collectively referring to alewife [*Alosa pseudoharengus*] and blueback herring [*Alosa aestivalis*]) and the catadromous American eel (*Anguilla rostrata*) were among the most widespread species (Perley, 1852; Knight, 1867; Dunfield, 1985). However, due to widespread habitat degradation and loss, tidal barriers and other obstructions to migration between spawning and other critical habitat, over-exploitation, and other human-imposed threats, many BoF diadromous fish populations are confirmed or suspected to have declined significantly from historic abundances or have become entirely extirpated (Knight, 1867; Vieth, 1868; Ambrose, 1890; Prince, 1903; Prince, 1910; Dunfield, 1985; Jessop, 1993; Percy, 1997; Percy and Wells, 1997; Jessop, 1999; Wells, 1999; Chaput and Bradford, 2003; Douglas et al., 2003; Gibson et al., 2003). Moreover, some species, most notably the inner BoF (iBoF) population of Atlantic salmon, may be currently threatened with extinction (Nova Scotia Department of Natural Resources [NSDNR], 2002; Committee on the Status of Endangered Wildlife in Canada [COSEWIC], 2004a).

Diadromous fishes in the Avon River Watershed (ARW), Nova Scotia have been facing considerable human-induced stresses since Europeans settled in the watershed in

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[1] ***Diadromous fishes*** are migratory species in which all, or the vast majority of, individuals migrate between marine and freshwater habitats as a routine and essential component of their life cycle (Myers, 1965; McDowall, 1988). There are two general types of diadromous species: ***anadromous and catadromous***. The former term refers to species which spend part of their lives at sea and/or in estuaries but migrate to freshwater systems to spawn. The latter term refers to species which spend most of their lives in freshwater systems but migrate to the sea to spawn.

1685, including dykes, fishing, logging, agriculture, municipal and industrial pollution, mill-dams, hydro power development, and a tidal barrier (Windsor Causeway) constructed in 1970 across the Avon estuary without fish passage facilities. Considerable uncertainty and disagreement exist regarding the effects of the causeway on diadromous fishes, particularly in regard to fish passage. Consequently, there is controversy surrounding what, if any, actions should be taken to address this stressor. As part of the twinning of Highway 101, the Nova Scotia Department of Transportation and Public Works has proposed the expansion or modification of the causeway to provide extra traffic lanes, which has further intensified concerns and questions regarding the threats posed by this tidal barrier to diadromous fishes[2].

Many biologists and local citizens strongly suspect that significant declines (and possibly the extirpation of the iBoF Atlantic salmon) have occurred in ARW diadromous populations, especially since the construction of the Windsor Causeway. However, to date, little research has been conducted on the ARW diadromous community, and there is considerable uncertainty in regards to its historic (prior to extensive human disturbance) and contemporary characteristics (including exact species composition and relative abundances), the specific nature and degree of degradation over time, and the individual and cumulative impacts of various human-induced stressors in the ARW. Without this information, it will be difficult to develop, and also to create community support and consensus for, appropriate and effective conservation and recovery actions, or to make appropriate local watershed management decisions (Kelso *et al.*, 1996; Steedman *et al.*, 1996; Pesch and Garber, 2001), such as those regarding the future of the causeway.

1.1 Goal and Objectives

The goal of this thesis is to characterize the historic status of, and the nature and degree of changes in, ARW diadromous fish populations, from European settlement (c. 1685) to the present (2004), and to examine the potential relationships between population changes and human-induced stressors. The purpose is to provide information

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[2] This will require an environmental impact assessment (EIA) on project options (an EIA was not conducted for the original construction since it was not a legal requirement at the time).

for local decision-making in regard to diadromous fish conservation/restoration, watershed management planning, and project options for the proposed modification/expansion of the Windsor Causeway.

The objectives are:

- to qualitatively characterize the historic (pre- and/or less-degraded) and current status of, and the nature and degree of changes in, diadromous fish populations, focusing on presence/absence and relative abundance of each species, by compiling and integrating scientific and anecdotal/qualitative sources of information; and,
- to identify and examine the potential impacts of major historic and contemporary human activities in the watershed and estuary on, and their contributions to changes in, diadromous populations.

Scientists and conservationists are increasingly recognizing the importance of interdisciplinary historical studies, such as this thesis, for directing and promoting conservation and restoration-orientated management efforts (Kelso *et al*., 1996; Steedman *et al*., 1996; Robertson *et al*., 2000; Pesch and Garber, 2001), although such research is not yet routinely undertaken as part of conservation/restoration planning or management decision-making processes (Robertson *et al*., 2000; Pesch and Garber, 2001). Historical information (such as that collected through this research) on the status of and changes to fish populations and the overall ecosystem and the factors that have led to current conditions can be used to define conservation/restoration goals and identify and evaluate the success of measures to achieve those goals (Ryder and Kerr, 1989; Kelso *et al*., 1996; Steedman *et al*., 1996; White and Walker, 1997; Robertson *et al*., 2000; Pesch and Garber, 2001). For example, historical studies can provide an understanding of the state of the pre- or less-degraded fish community/populations and ecosystem prior to extensive human disturbance, which can be used as a benchmark to characterize the nature and degree of human-induced degradation over time and to evaluate the current status of the fish community/populations and level of ecological intactness, thereby ascertaining conservation and recovery needs (Anderson, 1991; Steedman *et al*., 1996). Furthermore, the information provided by historical studies may foster support for mitigation, conservation, restoration, and/or stewardship efforts by raising the awareness of stakeholders and decision-makers about biotic declines and the role of human activities (Steedman *et al*., 1996; Pesch and Garber, 2001). Additionally, historic lessons can inform decision-making so that future problems may be avoided (Kelso *et al*., 1997; Steedman *et al*., 1997; Robertson *et al*., 2000).

1.2 Description of the Study Area

The Avon River, Nova Scotia is a tidal river system (consisting of the ARW and Avon estuary), which empties into the Minas Basin in the iBoF (Figure 1). The majority of the Avon River is located in the Municipality of West Hants in Hants County. Small portions are also located within the boundaries of Kings (northwest) and Lunenburg counties (southern headwaters). The ARW[3] is the study area of focus for this thesis (Figure 2). The study area is delineated as the area of the Avon River located upstream of the town of Windsor. Downstream of Windsor, the ARW system flows into the Avon estuary, which then empties into the Minas Basin. In 1970, the Windsor Causeway was constructed across the estuary between the towns of Windsor and Falmouth, imposing a distinct division between the ARW and estuary. Several other tributary river systems empty into the Avon estuary, the primary of which are the Kennetcook, St. Croix and Cogmugun Rivers on the east side and the Halfway River on the west side.

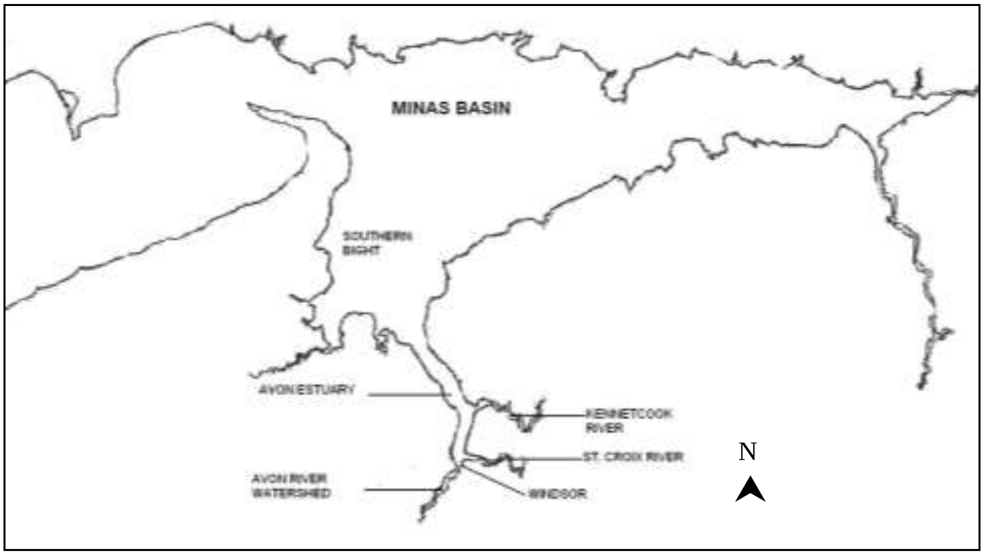

Figure 1: Location of Avon River in the Minas Basin

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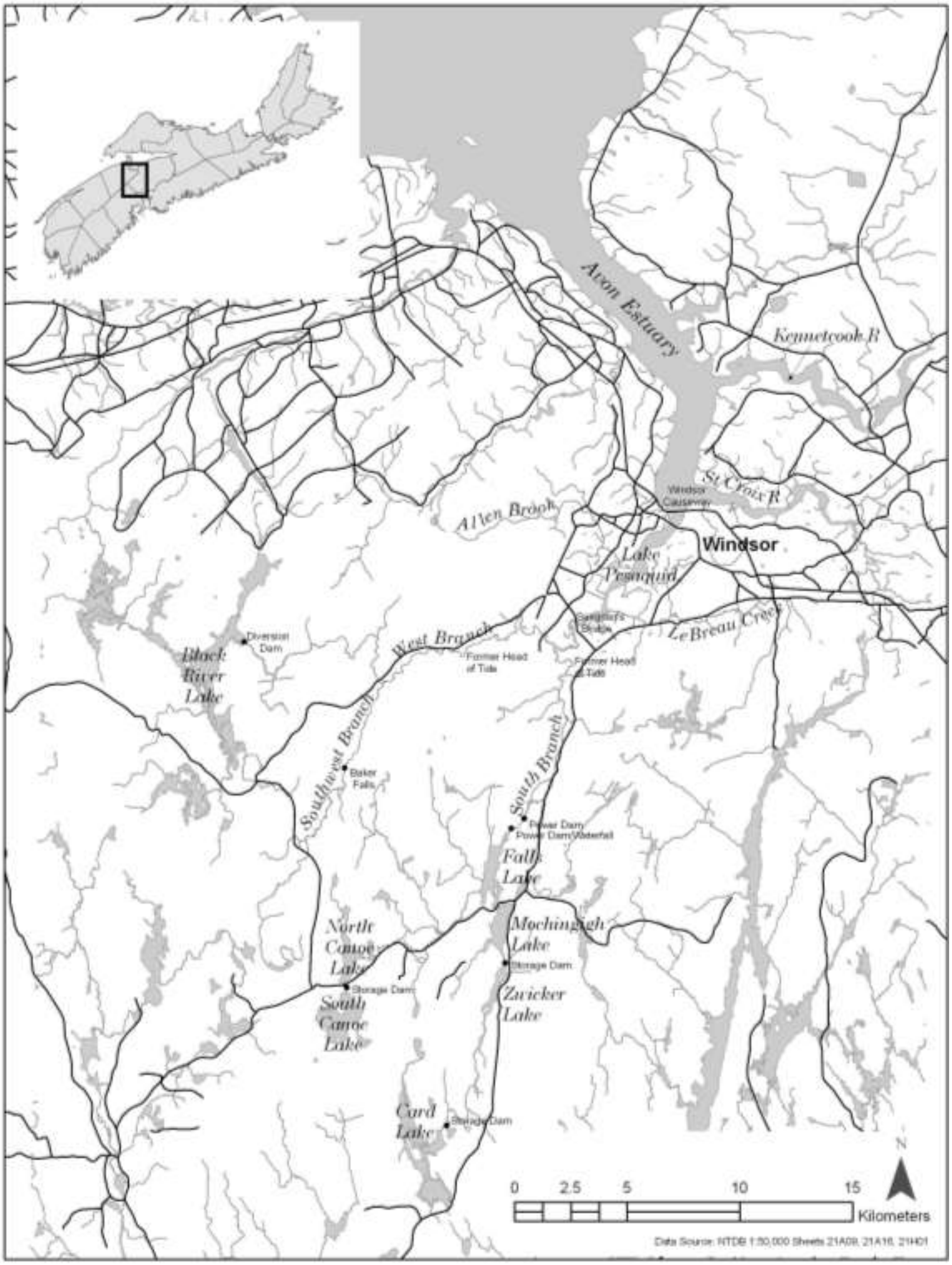
[3] In this thesis, ***lower ARW*** will refer to the portion of the watershed below the waterfalls on the South and Southwest branches and ***upper ARW*** to the area above.



Data Source: NTDB 1:50,000 Sheets 21A09, 21A16, 21H01

Figure 2: Map of Avon River Watershed Study Area and Avon Estuary

The ARW drainage area is approximately 460 km^2 and includes three main river branches (South, West, and Southwest), many streams and lakes, and since the completion of the Windsor Causeway, a headpond known as Pesaquid Lake (Conrad and Semple, 1987) (Figure 2). The ARW has been a primarily freshwater system since the construction of the causeway, which generally prevents tidal movements and saltwater intrusion into the ARW. Formerly, however, the tide extended several kilometres upstream (Daborn *et al.*, 2004); the original head of tide on the South Branch was approximately 16 km above Windsor (around the Windsor Forks area) and on the West Branch was approximately 5 km from the confluence with the South Branch (Smith, 1965). Major natural waterfalls are located on the South and Southwest branches; a 15 m high waterfall is located on the South Branch below Falls Lake (Venning, 1869) and a 12 m high waterfall, Bakers Falls, is located on the Southwest Branch, 4 km upstream of the confluence with the West Branch (Conrad and Semple, 1987). In the 1920s and 1930s, the ARW was developed for hydro-electric power generation. The Avon River hydro power system consists of a series of power dams, storage dams, and pipeline diversions (Shanks, 1994). There are two power dams on the lower South Branch (the first is located on the waterfall, the second 90 m downstream), a diversion dam on the West Branch at the outlet of Black River Lake, and storage dams on the outlets of four lakes in the upper ARW (see Chapter 5). The West Branch dam diverted water flow from Black River Lake, which previously formed the headwaters of the West Branch, into the neighbouring Gaspereau River system (Smith, 1965).

Rivers in the iBoF are generally characterized by good habitat diversity and complexity which makes them well-suited to the production of a variety of diadromous species, especially Atlantic salmon (Department of Fisheries and Oceans [DFO], 2003). The ARW is characterized by low rolling hills, with the lower part flowing through a wide valley (Maritime Marshland Rehabilitation Administration [MMRA], 1965). Due to the low relief, the rivers in this area are generally slow moving mature floodplain rivers (Davis and Browne, 1996). The geology of the ARW is complex: the upper portion of the watershed is underlain by granite, whereas the lower ARW and estuary are underlain by carboniferous deposits of sandstone, shale, limestone and gypsum (MMRA, 1965), which provides for good to excellent water quality for fish and a high buffering capacity against acid rain (Amiro, 2003). The average annual precipitation is 1000-1400 mm and average winter and summer air temperatures are -6 to -5°C and 17 to 19°C, respectively (Davis and Browne, 1996).

Chapter 2: Overview of Diadromous Species in the Minas Basin

2.1 Ecological Importance of Diadromous Fish Populations

Native diadromous fish provide numerous crucial ecological functions and are thus considered key components in the tidal river (freshwater and estuarine) and marine ecosystems which they inhabit (Willson and Halupka, 1995; Bilby *et al*., 1996). First, through a complex web of ecological relationships (e.g. competition, mutualism and predator-prey relationships), diadromous fishes play a key ecological role by influencing the structure and dynamics of terrestrial and aquatic biotic communities (Mills *et al*., 1992; Willson and Halupka, 1995; Kaiser and Jennings, 2002; Persson, 2002). For example, many diadromous fishes are keystone food sources for other fish, mammals and birds in freshwater systems (Mills *et al*., 1992; Willson and Halupka, 1995). Moreover, some diadromous fishes are key predators that control and maintain the abundance of prey species such as other fish and benthic invertebrates (Mills *et al*, 1992; Persson, 2002). Therefore, the decline or loss of a particular fish population can have drastic consequences for the productivity of natal watersheds and the conservation of biodiversity, including other diadromous fish (Gibson and Myers, 2003). Although the effects may be most pronounced in watershed ecosystems, changes in discreet populations may also have consequences for the structure and stability of marine biodiversity, especially when considering the cumulative contribution of many river populations (Wells, 1999).

Second, the maintenance of individual river populations is important for the stability of the entire species by contributing to total abundance and genetic and behavioural diversity (Willson and Halupka, 1995; Douglas *et al*., 2003). Therefore, population extirpations can affect a species' ability to adapt to environmental and/or human-induced changes, thus rendering it more vulnerable to extinction.

Third, diadromous species are important vectors for nutrient transport between freshwater and estuarine/marine systems. During spawning migrations, large numbers of anadromous fish, especially alewives and salmonids, die of natural causes releasing marine-derived nutrients into freshwater ecosystems, which supports and enhances the productivity of aquatic organisms (Durbin *et al*., 1979; Bilby *et al*., 1996; Stockner and MacIsaac, 1996) and riparian vegetation (Helfield and Naimon, 2001). Reductions in diadromous fish abundances (e.g. caused by obstructions to upstream fish migration) have often been found to result in significant decreases in freshwater ecosystem productivity (Bilby *et al*., 1996; Stockner and MacIsaac, 1996). Although most of the studies of this process have been performed on the west coast, Durbin *et al*. (1979) suggested that nutrient input from fish into freshwater ecosystems may be comparable, if not greater, in east coast rivers. Since nutrients from upstream freshwater systems are carried downstream by out-going tides (if not impeded by barriers), they may also add to the productivity of estuaries and coastal ecosystems (Wells, 1999).

Fourth, the sensitivity of many diadromous species to ecological changes in habitat conditions makes them useful indicators of human-induced disturbance to the ecosystem integrity of watersheds (Nehlsen *et al*., 1991; Warren and Burr, 1994). Finally, holistic ecosystem-based strategies, especially at a watershed-level, are usually necessary (and increasingly employed) for the effective conservation and/or restoration of diadromous populations or assemblages (Sheldon, 1988; Willson and Halupka, 1995; Kelso *et al*., 1996; Steedman *et al*., 1996). Such strategies aimed at a diadromous species or suite of species of particular conservation concern typically provide concurrent conservation benefits for other sympatric (present in the same location) species and for the overall ecological integrity and biodiversity of the entire watershed (Kanno and Beazley, 2004).

2.2 Diadromy in the Minas Basin/Bay of Fundy

Fifteen native diadromous species have been identified in the tidal river systems within the Minas Basin/BoF (Table 1). Nine of the species are generally classified as obligatorily anadromous, meaning migration between fresh and saltwater is essential for the completion of their life cycle/reproduction (McDowall, 1988). However, a few populations of some of these species (salmon, smelt) have become land-locked, although there is no evidence of such a phenomenon in ARW populations. Brook trout (*Salvelinus fontinalis*), white perch (*Morone Americana*), and three species of sticklebacks (*Gasterosteus aculeatus*, *Apeltes quadracus*, and *Pungitius pungitius*) are considered to be facultatively anadromous, meaning that the species are comprised of both anadromous and non-migratory populations (some populations exist entirely in freshwater or estuarine/marine waters). Moreover, within single populations with anadromy, a certain proportion may be non-migratory, along with the anadromous segment (Northcote, 1967; McDowall, 1988). When sympatric, the migratory and non-migratory individuals may interbreed. Moreover, individuals that are migratory may not do so every year (Scott and Scott, 1988). The reasons for the variations in the migratory behaviour of individuals of these species are uncertain but may be related to climatic conditions, food availability, or space limitations (McDowall, 1988). The remaining species, American eel, is the only known catadromous species in North America (Scott and Scott, 1988; Jessop, 2000).

Table 1: List of Diadromous Species Identified in Minas Basin Rivers and Their Life History Strategies

Common Name	Scientific Name	Life History Strategy
Atlantic sturgeon	*Acipenser oxyrynchus*	Anadromous
Blueback herring*	*Alosa aestivalis*	Anadromous
Alewife*	*Alosa pseudoharengus*	Anadromous
American shad	*Alosa sapidissima*	Anadromous
American eel	*Anguilla rostrata*	Catadromous
Fourspine stickleback	*Apeltes quadracus*	Facultatively Anadromous
Threespine stickleback	*Gasterosteus aculeatus*	Facultatively Anadromous
Atlantic tomcod	*Microgadus tomcod*	Anadromous
White perch	*Morone Americana*	Facultatively Anadromous
Striped bass	*Morone saxatilis*	Anadromous
Rainbow smelt	*Osmerus mordax*	Anadromous
Sea lamprey	*Petromyzon marinus*	Anadromous
Ninespine stickleback	*Pungitius pungitius*	Facultatively Anadromous
Atlantic salmon (iBoF population)	*Salmo salar*	Anadromous
Sea-run brook trout (sea-trout)	*Salvelinus fontinalis*	Facultatively Anadromous

* The term gaspereau is used to collectively refer to alewife and blue-back herring.
Sources: Scott and Scott (1988), Davis and Browne (1996)

The diadromous fishes may utilize the tidal river systems (including fresh and estuarine/brackish waters) in the Minas Basin/BoF region for spawning, rearing, feeding and/or other crucial habitat during various stages in their life cycles. Spawning populations of the majority of the anadromous species are fairly common, at least historically, among accessible BoF tidal river watersheds (see Section 2.3). However, there are few rivers that are confirmed to have supported historic spawning populations of American shad (*Alosa sapidissima*) (Chaput and Bradford, 2003), striped bass (*Morone* *saxatilis*) (Douglas *et al*., 2003), Atlantic sturgeon (Percy, 1997), or sea lamprey (*Petromyzon marinus*) (Beamish, 1980) in Atlantic Canada, of which the Avon River was not included prior to this study. Nevertheless, since there has been a lack of scientific research and documentation on fish in many BoF watersheds (Percy and Wells, 1997), including the Avon River, there is the possibility of the existence of other historic runs (Beamish, 1980; Rulifson and Dadswell, 1995; Chaput and Bradford, 2003).

Many anadromous species exhibit some degree of homing fidelity, which is the tendency to return to the specific river system, or even stream, lake or site of their birth to spawn (McDowall, 1988). The anadromous species in the BoF appear to have fairly strong homing fidelities to natal river systems (see Section 2.3). Since the occurrence of straying to (spawning in) non-natal rivers is probably small, there can be a high degree of genetic isolation and differentiation between individual populations (Douglas *et al*., 2003; Waldman and Wirgin, 1998).

2.3 Species Profiles

The following is a brief description of the distribution of the key diadromous species in the Minas Basin/BoF and some important life history attributes (e.g. reasons for entering tidal rivers in BoF, timing of riverine migrations).

2.3.1 Atlantic Salmon

General: Atlantic salmon stocks from rivers in the iBoF, including the MB region, have been recognized as belonging to a genetically distinct population of *Salmo salar*, which generally has life history traits that differ from outer BoF and Atlantic coast salmon (Amiro, 2003).

Occurrence of spawning populations: At least 32 rivers in the iBoF (18 in the Minas Basin) are known to have extant salmon runs (DFO, 2003). However, DFO (2003) asserted that rivers in these areas are generally well-suited to salmon production and most unobstructed rivers and streams are suspected to have had historic runs.

Migrations and spawning: iBoF salmon populations undertake upstream spawning migrations in the spring and/or fall (DFO, 2003). Spawning occurs in October and November (Scott and Scott, 1988). Unlike Pacific salmon, Atlantic salmon do not usually die after spawning. Most spent adults move downstream to rest in a pool or estuary for a few weeks before returning to sea. However, some may return to sea immediately or may over-winter in the river and return to sea in the spring. Many will return to spawn a second time, and a few, a third or more. iBoF salmon have been found to have a higher rate of survival between spawning events than other Atlantic salmon populations (Amiro *et al*., 2003). Most juvenile iBoF salmon remain in freshwater for several (two to three) years before migrating to saltwater (Amiro, 2003). Seaward migration generally occurs in May and June, but has been observed as late as July in some populations.

Degree of Homing fidelity: Homing fidelity is very high. Although a few may stray, the majority of Atlantic salmon return to their native streams to spawn (Scott and Scott, 1988).

2.3.2 Sea-Run Brook Trout (Sea-Trout)

Occurrence of spawning populations: Anadromous brook trout (from now on will be referred to as sea-trout) are widespread throughout rivers in the Minas Basin/BoF (Nova Scotia Department of Agriculture and Fisheries [NSDAF], 2001a)

Migrations and spawning: Sea-trout typically descend from freshwater to river estuaries or marine waters from late April to early June (Scott and Scott, 1988; NSDAF, 2001a). The fish live in saltwater for an average of two to three months, usually migrating back to freshwater in July and August (Scott and Scott, 1988); however, some have been found to over-winter in estuaries (NSDAF, 2001a). Resident and sea trout in NS spawn in October and November (NSDAF, 2001a).

Degree of homing fidelity: Homing fidelity is very high; sea-trout generally remain near and return to their native river systems (Scott and Scott, 1988; NSDAF, 2001a).

2.3.3 Alewife and Blueback Herring (Gaspereau)

General: The alewife and blueback herring are two similar, often sympatric, species of alosids (Loesch, 1987). These species are difficult to differentiate and thus are usually collectively referred to as gaspereau.

Occurrence of spawning populations: Historic populations of both species occur in most of the accessible rivers in the Minas Basin/BoF (Jessop, 1999).

Migrations and spawning: In the BoF, alewife spawning migrations begin in late April or early May and end by mid-July (Jessop, 1999). Blueback herring runs typically begin two to three weeks later. Many adults of both species die after spawning (Loesch, 1987); however, a high percentage of adult gaspereau in Nova Scotia rivers are repeat spawners, with higher proportions in rivers with low exploitation levels (Jessop, 1999). Those that survive may return to sea almost immediately (Loesch, 1987). From mid-summer to late fall, young-of-the-year (YOY) migrate downstream to estuaries and coastal waters (Stokesbury and Dadswell, 1989; Gibson and Myers, 2003; Daborn *et al*., 2004).

Degree of homing fidelity: Homing fidelity is generally high in both species; however, some may stray (Jessop, 1999). For example, Loesch (1987) noted that, in several instances, gaspereau had been observed colonizing systems that were previously inaccessible, when physical or hydrological conditions had changed (e.g. removal of dams or other obstructions).

2.3.4 Rainbow Smelt

Occurrence: Historic runs are believed to have occurred in most rivers of the Minas Basin/BoF (Percy, 1997).

Migrations and spawning: In the fall, smelt move into tidal river estuaries, where they remain over winter (Scott and Scott, 1988). After spring thaw, spawning fish migrate up to streams to spawn. Spawning season in Nova Scotia occurs in April and May, and occasionally, June (Daborn *et al*., 2004). Many adults die after spawning. Those that survive migrate back to estuaries and coastal waters for the summer. After larvae hatch in May and June, they drift down into estuaries (Daborn *et al*., 2004), where they remain over summer (Jessop, 1993).

Degree of homing fidelity: Homing fidelity is generally high. Smelt usually return to their native stream to spawn, but they may also move to other, especially nearby, streams (NSDAF, 2001b).

2.3.5 American Shad

Occurrence of spawning populations: Only a few rivers in the BoF are known to have supported historic spawning populations of American shad. There are two confirmed runs in the Minas Basin (Shubenacadie and Stewiacke Rivers) (Chaput and Bradford, 2003). Evidence for extant or historical runs in other rivers is vague.

Migrations and spawning: In the few known BoF shad populations, upstream migrations and spawning activity generally occur in May and June (Leim, 1924; Williams and Daborn, 1984). Shad generally do not die after spawning and in BoF populations, high proportions (e.g. 89% in Annapolis River) are repeat spawners (Melvin *et al*., 1985; Chaput and Bradford, 2003). After hatching, the young spend a brief time in freshwater before migrating downstream to brackish water in the late summer to early fall (Scott and Scott, 1988; Stokesbury and Dadswell, 1989).

Other uses of BoF/Minas Basin rivers: Shad from most Canadian and American stocks migrate to the BoF and often enter non-natal river estuaries to feed (Chaput and Bradford, 2003).

Degree of homing fidelity: Typically very high proportions return to rivers of previous spawning to spawn. For example, in the Annapolis River, Melvin *et al*. (1986) found homing fidelity to be as high as 97%.

2.3.6 Striped Bass

Occurrence of spawning populations: Only three river systems in the BoF are confirmed to have supported historic spawning populations of striped bass, of which only one (Shubenacadie-Stewiacke Watershed, NS) is extant (Douglas *et al*., 2003). The remaining two (Saint John River, NB, and Annapolis River, NS) appear to have been extirpated within the last 40 or 50 years.

Migrations and spawning: BoF striped bass spawn in the spring, several weeks after the ice melts (Rulifson and Dadswell, 1995). Upstream spawning migrations begin in April and spawning occurs from late May to early June (Rulifson and Dadswell, 1995; Rulifson and Tull, 1999). Spawning activity occurs near the head of tide in fresh to brackish water. After spawning most adults migrate downstream in spring to enter coastal waters (Rulifson and Dadswell, 1995; Douglas *et al*., 2003).

Other uses of BoF/Minas Basin rivers: During summer coastal migrations, like shad, adult and juvenile striped bass from many Canadian and American stocks enter BoF tidal river estuaries on flood tides, pursuing prey fish (Rulifson and Dadswell, 1995).

Moreover, in late fall many striped bass ascend both natal and non-natal rivers where they over-winter in freshwater pools and ponds (Douglas *et al*., 2003). Many rivers in the Minas Basin may be or have been used for this purpose (Wirgin et al., 1995; Douglas *et al*., 2003). Douglas *et al*. (2003) speculated that this over-wintering behaviour, at least in some cases, may be undertaken to avoid low, potentially lethal winter seawater temperatures. In early May, over-wintering fish begin their downstream migration, either to spawning grounds (if in natal river) or directly back into estuaries (if in non-natal river).

<u>Degree of homing fidelity</u>: Homing fidelity is very high. Robinson and Courtenay (1999) summarized the findings of genetic investigations on Maritime striped bass, which revealed that there is a high degree of genetic distinctiveness and therefore a low rate of gene flow between populations. Striped bass will not normally spawn in other rivers, even when present in spawning grounds during spawning season (e.g. after over-wintering) (Douglas *et al*., 2003). Additionally, each population has an extremely narrow breeding range, often localized to a specific site of no more than a few km^2 in a single tributary of a single river.

2.3.7 Atlantic Sturgeon

<u>Occurrence of spawning populations</u>: There are no rivers in the Minas Basin known to have supported historic spawning populations of sturgeon. In fact, only one river in the BoF (Saint John River, NB) has a documented (confirmed) population (Percy, 1997).

<u>Migrations and spawning:</u> From May to July, Atlantic sturgeon migrate up Canadian rivers to spawn in freshwater (Smith and Clugston, 1997). After spawning, spent adults gradually return to sea (Scott and Scott, 1988). Although sturgeon are repeat spawners, females do not reproduce annually (Waldman and Wirgin, 1998). Smith and Clugston (1997) believe that juveniles undertake a gradual downstream migration to lower tidal reaches and estuarine areas of rivers; however, the timing in unknown. Most juveniles remain in brackish waters for several months to three or four years, after which they move into coastal waters (Scott and Scott, 1988; Smith and Clugston, 1997). Atlantic sturgeon reach sexual maturity between the ages of 10 to 25 years (Waldman and Wirgin, 1998).

Other uses of BoF/Minas Basin rivers: Sturgeon from other Canadian and American rivers are known to frequent the BoF and are especially common in the Minas Basin during the summer months, where they enter non-natal tidal river mouths and estuaries to feed (Percy, 1997; Waldman and Wirgin, 1998).

Degree of homing fidelity: Homing fidelity is very high. Waldman and Wirgin (1998) found that the rate of gene flow between sturgeon populations was extremely low (e.g. only 1.3 reproducing migrants per generation between Canadian and Hudson River stocks). Moreover, populations were found to generally exchange less than one female per generation. This suggests that homing fidelity is high and straying is rare, especially among females. Nevertheless, some straying appears to occur, mainly with neighbouring populations.

2.3.8 Atlantic Tomcod

Occurrence of spawning populations: Spawning aggregations of Atlantic tomcod (*Microgadus tomcod*) occur in many BoF rivers (Percy, 1997).

Migrations and spawning: The tomcod is a small estuarine forage fish (Stewart and Auster, 1987). In late fall and early winter (November to February, with peak in January), this species migrates to brackish or freshwater to spawn. Tomcod will also often spawn in estuarine waters of low salinity. Soon after spawning adults migrate back to estuaries (Fortin *et al*., 1990). In the early spring, the young drift downstream into natal estuaries where they often remain (Peterson *et al*., 1980).

Degree of homing fidelity: Uncertain.

2.3.9 Sea Lamprey

Occurrence of spawning populations: Knowledge of sea lamprey in the BoF is sparse. Beamish (1980) found sufficient evidence to confirm spawning populations in only 16 rivers in Nova Scotia. However, the author argued that others are likely to exist or have existed.

Migrations and spawning: In Atlantic Canada, sea lamprey spawning migration and activity takes place between March and September (Beamish, 1980). Adults die after spawning. Young remain in natal streams for six to eight years, after which juveniles migrate downstream in late fall or early spring. Juveniles remain at sea for two to three years before returning to rivers to spawn.

Degree of homing fidelity: Uncertain

2.3.10 American Eel

Occurrence: American eels are widespread in rivers throughout the Minas Basin/BoF (Scott and Scott, 1988).

Migrations and spawning: American eels generally spend approximately 20 years (and sometimes longer) foraging, growing, and maturing in freshwater before migrating to the Sargasso Sea to spawn (Jessop, 2000). Downstream spawning migrations usually begin in the late summer and fall. Peak spawning in the Sargasso Sea occurs between February and April, after which spent adults die. Glass eels (larvae) usually enter Canadian river estuaries in May and June. However, upstream migration to freshwater may take several years.

Degree of homing fidelity: All eels return to the Sargasso Sea to spawn (Avise *et al*., 1986). Eels do not home to the river of their parents' development, which would most likely be different for each parent. However, Lamothe *et al*. (2000) summarized evidence that developing eels home to specific freshwater and estuary habitat sites and are able to and have a tendency to return to these 'home' sites, even from long distances, if artificially or naturally displaced.

2.4 Sensitivity of Diadromous Fishes to Human-Induced Threats

Although exposed to natural and human-induced stressors throughout their ranges, human activities in tidal river watersheds appear to pose the most significant threats to the status of diadromous populations and species. The most serious and widespread threats to diadromous species are typically considered to be habitat degradation and loss, obstructions to migration to and from spawning and other critical habitats, water pollution, native and non-native fish introductions, and exploitation (Miller *et al*., 1989; Richter *et al*., 1997; Reynolds *et al*., 2002).

Diadromous species have particular habitat preferences and requirements and exhibit varying degrees of tolerance to chemical, physical, and biological habitat alteration and degradation (Table 2). Intolerant species, such as the salmonids, have more specialized habitat needs and thus have higher sensitivities to ecological changes in spawning, rearing, or other key habitat components (Karr *et al*., 1986; Lyons *et al*., 1996). Consequently, they are often the first to decline or disappear from a system in response to human-induced habitat alterations. However, even tolerant species can be seriously affected by major habitat disturbances or changes in important habitat or water quality variables.

Table 2: Habitat Preferences of Diadromous Species Identified in Minas Basin/Bay of Fundy Rivers

Species	Habitat[1]	Temperature Preference Class[2]	Tolerance to Habitat Disturbance[3]
Atlantic sturgeon	Rivers	Cold/Cool-water	Intolerant
Blueback herring	Rivers	Cold-water	Intermediate/moderate
Alewife	Streams + Lakes	Cold-water	Intermediate/moderate
American shad	Rivers	Cold-water	Intermediate/moderate
American eel	Streams + Lakes	Cool-water	Tolerant
Fourspine stickleback	Streams	Cold-water	Intermediate/moderate
Threespine stickleback	Streams + Lakes	Cold-water	Intermediate/moderate
Atlantic tomcod	Streams + Lakes	Cold-water	Intolerant
White perch	Rivers + Lakes	Warm-water	Intermediate/moderate
Striped bass	Rivers	Cool-water	Intolerant
Rainbow smelt	Streams + Lakes	Cold-water	Intolerant
Sea lamprey	Rivers + Lakes	Cold-water	Intermediate/moderate
Ninespine stickleback	Streams + Lakes	Cold-water	Intermediate/moderate
Atlantic salmon	Streams + Lakes	Cold-water	Intolerant
Brook (sea) trout	Brooks + Lakes	Cold-water	Intolerant

Notes and Sources:

[1] Scott and Crossman (1973); Halliwell *et al*. (1998); Coker *et al*. (2001)

[2] Based on Coker *et al*. (2001)'s classification of fishes in Canadian waters
Categories: Warm-water (>25ºC); Cool-water (19-25ºC); Cold-water (<19ºC)

[3] Based on Halliwell *et al*. (1998)'s classification of fishes in Northeastern United States

Migratory species require free passage between freshwater and saltwater habitats to complete their life cycles and thus are sensitive to human-made impediments to migration (Richter *et al*., 1997; Wells, 1999; World Wildlife Fund [WWF], 2001). Since few individuals are likely to seek or spawn in other areas with suitable conditions, species with high homing fidelities would be especially susceptible to local population extirpations as a result of habitat destruction and obstructions to natal spawning grounds.

Moreover, species with low intrinsic rates of increase, such as the late maturing Atlantic sturgeon, may be especially sensitive to declines in abundance and local extirpations caused by artificially high mortality rates (e.g. caused by exploitation or pollution) since they are slow to replenish their numbers (Smith and Clugston, 1997; Waldman and Wirgin, 1998).

2.5 Status of Diadromous Species in the Bay of Fundy

As of November 2004, COSEWIC had assessed the conservation status of 128 freshwater and marine fish species in Canada, 83 (mostly freshwater and diadromous species) of which were determined to be species-at-risk (endangered, threatened or of special concern) (COSEWIC, 2004a). J. Hutchings (2003, pers.comm.) suggested that since the assessment of fish has not been a priority until recently, the current list is likely to represent only a small fraction of the total number of at-risk species.

Within the BoF region, the status of most of the diadromous species, especially salmon, shad, striped bass, gaspereau, sea-run trout and smelt, has drastically deteriorated from historic conditions to the point that many of the known historic runs have become severely depleted or entirely extirpated (Knight, 1867; Prince, 1910; Dunfield, 1985; Jessop, 1993; Percy, 1997; Jessop, 1999; Chaput and Bradford, 2003; Douglas *et al*., 2003; Gibson *et al*., 2003). Due to the increasing magnitude and pervasiveness of threats from human activities, the most drastic changes appear to have occurred in modern times (Percy, 1997). However, serious problems in, at least, the key fishery species (especially salmon and shad) have been noted throughout much of the 19th and 20th centuries (Perley, 1852; Knight, 1867; Vieth, 1868; Prince, 1910; Dunfield, 1985). The genetically distinct iBoF population of Atlantic salmon and remaining BoF population of striped bass have been designated as federally at-risk by COSEWIC (endangered and threatened, respectively) (COSEWIC, 2004a; 2004b) (Table 3). Moreover, six species (including salmon and striped bass) have been ranked as being potentially at-risk of extinction or sensitive within Nova Scotia (NSDNR, 2002). The iBoF Atlantic salmon is at the most serious and immediate risk of extinction (COSEWIC, 2004a). Since the mid-20th century, the total abundance has dropped from as much as 40,000 wild adults to less than 200 in 2003, with the most pronounced declines (90%) occurring since 1990 (Amiro, 2003;

DFO, 2004). Moreover, in 2002, electro-fishing surveys were conducted in 38 known historic iBoF salmon rivers, and in 19, no evidence of salmon was found (Gibson *et al*., 2003). Reflecting its precarious status, DFO (2004, p.1) determined that "any level of human-induced harm could jeopardize survival or recovery of this genetically distinct salmon".

Table 3: National and Nova Scotia Status Ranks for Diadromous Species in the Minas Basin/Bay of Fundy

Species	National[1]	Nova Scotia[2]
Atlantic sturgeon	NA	Red-listed
Blueback herring	Not at-risk (assessed in 1980)	Green-listed
Alewife	NA	Yellow-listed
American shad	NA	Green-listed
American eel	NA	Green-listed
Fourspine stickleback	NA	Yellow-listed
Threespine stickleback	NA	Green-listed
Atlantic tomcod	NA	Green-listed
White perch	NA	Green-listed
Striped bass (BoF population)	Threatened (assessed in 2004)	Red-listed
Rainbow smelt	NA	Green-listed
Sea lamprey	NA	Green-listed
Ninespine stickleback	NA	Green-listed
Atlantic salmon (iBoF population)	Endangered (assessed in 2001)	Red-listed
Brook trout	NA	Yellow-listed

[1] *Endangered*-facing imminent extirpation or extinction; *Threatened*-likely to become endangered if limiting factors are not reversed; *Not at-risk*-been evaluated and found to be not at-risk of extinction given the current circumstances; *NA*-has not been assessed, to date.

[2] *Red-listed*-at risk or maybe at-risk of immediate extirpation or extinction; *Yellow-listed*-not believed to be at-risk of immediate extirpation or extinction, but which may require special attention or protection to prevent from becoming at-risk; *Green-listed*-may have declined in numbers, but not believed to be at-risk or sensitive, and remain relatively widespread or abundant.

Sources: NSDNR (2002); COSEWIC (2004a)

Chapter 3: Methods

Research was undertaken to collect and qualitatively integrate existing historic and contemporary information on diadromous fishes in the ARW and potential human activities influencing them. Based on suggestions in the historical analysis literature (Steedman *et al*., 1996; White and Walker, 1997; Pitcher, 1998; Preikshot, 1998), a variety of interdisciplinary (both scientific/quantitative and anecdotal/qualitative) sources were explored in this study in order to develop as comprehensive and accurate an understanding as possible of past states, the pattern of change over time, and the potential cause and effect relationships with human stressors. The scientific/quantitative sources include scientific surveys and studies, fishery catch statistics, and museum specimens. The anecdotal/qualitative sources take the form of written observations (e.g. historic documents) and personal interviews with local knowledge holders such as resource users, local inhabitants, and fishery officers. Since little scientific or quantitative catch data exist for the diadromous (or freshwater) fishes in the ARW, this study primarily relies on anecdotal sources of information. Preliminary findings of this study have been previously published in Isaacman and Beazley (2005).

3.1 Data Collection and Sources

Data collection involved two concurrent phases: 1) local and expert key informant (KI) interviews; and 2) an exploration of existing scientific and anecdotal recorded data. The exploration-of-recorded-data phase consisted of four components: written records (historical, archival and contemporary documents), fisheries catch statistics, existing scientific fish surveys and museum specimens. In addition, throughout the research process, numerous relevant professionals (e.g. government, academics, non-government organizations) familiar with diadromous fish issues in the ARW were consulted to elicit their expertise and to identify contacts and sources of information (Table 4).

Table 4: List of Principle Consulted Experts and Professionals*

Name	Position	Organization
Bradford, Rod	Diadromous Assessment/ Species at Risk Biologist	DFO, Diadromous Fish Division
Brylinsky, Mike	Professor & Acting Director	Acadian Centre for Estuarine Research, Acadia University
Carroll, Ken	Aboiteau Superintendent	NSDAF
Crandlemere, Tara	Fisheries Technician	NSDAF, Inland Fisheries Division
Crowell, Art	Senior Technician	NSDNR
Daborn, Graham	Former Director & Professor	Acadian Centre for Estuarine Research, Acadia University
Davis, Lynn	Director of Planning	Windsor-West Hants Planning Department
Gibson, Jaime	Population Biologist	DFO, Diadromous Fish Division
Gilhen, John	Curator Emeritus, Ichthyology & Herpetology	Nova Scotia Museum of Natural History
LeBlanc, Jason	Fisheries Biologist	NSDAF, Inland Fisheries Division
Hebda, Andrew	Curator of Zoology	Nova Scotia Museum of Natural History
Hutchings, Jeff	Professor	Dept. of Biology, Dalhousie University
MacMillan, John	Biologist	NSDAF, Inland Fisheries Division
Meade, Ken	Environmental Supervisor	Nova Scotia Power Inc.
Powell, Steven	Assistant Curator of Archaeology	Nova Scotia Museum
Sabean, Barry	Director of Wildlife	NSDNR
Stevens, Greg	Senior Advisor, Anadromous and Freshwater Fisheries	DFO, Fisheries Management Branch
Sweeney, Hank	Fishery Officer	DFO

*This list comprises the individuals who contributed key knowledge, expertise, advice or other time and assistance to the study, including those who participated as expert key informants. Many other government, non-government, and academic experts were contacted, who provided limited advice, directed the researcher to other sources or experts, or were unable to contribute any notable relevant information or expertise on the subject.

All the diadromous species known to exist in the BoF were included in the study. Specifically, an attempt was made to find historic and contemporary information, from European settlement to the present, on: 1) presence/absence, relative abundance, key habitat locations, and evidence of spawning for each of the species in the ARW; 2) habitat conditions; and 3) potentially harmful human activities and any direct indication of their impacts. A brief exploration for information prior to European settlement was also conducted. The Avon estuary contains fish from ARW and local tributary populations, and non-local migrants. Therefore, a species' presence and abundance in the Avon estuary does not necessarily reflect the existence of a self-sustaining ARW spawning population. Consequently, information specifically referring to fish in the ARW was targeted. However, since diadromous fishes must pass through and may, in some cases, remain for some time in the estuary, potential human-induced stresses throughout the Avon River system (ARW and estuary) were considered.

3.1.1 Key Informant Interviews

Twenty-nine local and expert KI interviews were conducted between April and September 2004. Local KIs are individuals who were identified as holding long-term anecdotal knowledge of the diadromous fish, fish habitat, and human activities in the ARW. Since it was desired that KIs have a conception of both pre- and post-Windsor Causeway conditions and could describe changes over long timeframes, older individuals, particularly with a minimum of 35 years of personal knowledge and experience in the ARW, were sought. Moreover, recreational fishers were specifically targeted for the study since resource users often develop detailed observational knowledge of their resources and their environment (Neis et al., 1999). Other long-term inhabitants of the Avon River area who were identified as having local knowledge were also included. The target for expert KI interviews were Provincial and Federal government fisheries and natural resource officers (DFO, NSDAF, NSDNR) and fish and aquatic biologists (government and academic) with professional and/or personal local knowledge of the diadromous fishes and potential threats in the ARW.

Several methods were used to identify potential local and expert KIs. Throughout the interview period, names of potential participants were sought from professional (government and academic) contacts. Four local angling and environmental organizations were also contacted. Each of the groups' representatives was asked if they could identify potentially qualified members. In addition, at the suggestion of the groups' representatives, the researcher attended the June 2004 meeting of the West Hants Wildlife Association (a local angler/hunter organization), and a community discussion forum held by the Avon River Watershed Coalition (a local environmental group) in July 2004 on environmental and natural resource concerns in the watershed. The latter meeting was advertised in the local newspaper and in attendance were members of the Watershed Coalition, other environmentally-concerned local citizens, government representatives (DFO), and scientists with expertise on the local ecology and environmental concerns. At both meetings, the researcher made a brief presentation to introduce the study and request the participation of qualified individuals in attendance. Contact information was obtained from interested individuals. The two other local environmental groups (Friends of the Avon River, Wildlife Habitat Advocates) did not hold meetings during the interview period. Two regional angling organizations (Atlantic Salmon Federation and Trout Unlimited) were also contacted. An article about the thesis research was written in the June 9, 2004 edition of The Hants Journal, a local newspaper, which requested that local knowledge holders contact the researcher (Lawrence, 2004). This elicited only one response from the community, who was determined, through a telephone conversation with the researcher, not to have sufficient knowledge to warrant being interviewed for the study. Further potential KIs were identified using the snowball sampling technique, which involves asking participants to provide names of others individuals who might be appropriate for the study (Babbie, 1992). This is a common technique used to identify local ‘experts’ in local knowledge studies (Neis *et al*., 1999). In addition, names were also sought from the potential participants contacted who did not end up being interviewed.

Through these methods, 63 potential KIs were identified. Attempts were made to contact them via telephone or email. Twenty-nine interviews were arranged: 21 local and eight expert. Fifteen local KIs were former or on-going recreational fishers, four were non-fisher long-term Avon River area residents, and two were long-term residents who had fished (one former and one on-going) commercially in the Avon estuary. Local KIs had on average 50 to 60 years (to a maximum of 75 years) of personal experience in the watershed. Recreational fishers provided the most detailed knowledge of diadromous fishes in the ARW. Expert KIs consisted of four biologists and four fisheries/natural resources personnel. The potential KIs who were not interviewed did not believe that they had sufficient knowledge to contribute to the study, were unavailable during the interview period, or could not be reached.

A semi-structured, open-ended interview technique was used since it has been found to be one of the most effective methods for collecting local ecological knowledge (Mailhot, 1994). Following this technique, an interview schedule was used as a guide, but the actual progression of the interview was dependant on the nature and direction of the KI's comments. Questioning in the local KI interviews focused on eliciting actual observations, although many also discussed their opinions and interpretations of phenomena (e.g. causes of changes). Although personal observations and experiences tend to be the most useful and accurate (Robertson *et al*., 2000), local KIs were also encouraged to recount the direct observations of other individuals that they believed to be reliable (e.g. friends or family members).

In general, interviews began with the KI describing how long they had lived in the Avon River area and the nature of the sources (personal observations or second-hand accounts) of their knowledge on the diadromous fish and human activities in the watershed. Fishers were specifically asked to describe their fishing experience, including in what years and locations they fished, how often they fished during those years, and the species they targeted. The main focus of the interviews was on eliciting the KI's knowledge on the status of, and changes in, diadromous species. KIs were asked to identify all the species they were aware of in the ARW (past and/or present). For each species, KIs were directed to describe the relative abundance, time of year and locations observed, evidence of spawning, and the nature and timing of any changes they had noticed (or had heard of) over time. To ensure that species were not simply overlooked, KIs were also questioned about any species not initially mentioned. Finally, KIs were guided to identify and discuss potentially harmful human activities in the ARW and estuary and any evidence of their impacts, including observed changes in habitat conditions. Expert KI interviews followed a similar format, except that the primary aim was to elicit the expert's professional expertise and opinions on the status of ARW diadromous fishes and the most likely causes of changes. However, local knowledge obtained through their professional capacity or personal experiences (e.g. fishing) was also sought from expert KIs.

Interviews lasted between 45 minutes and two hours in duration. Expert KIs were interviewed in their place of employment. The majority of local KI interviews were conducted in the participant's home or in a local coffee shop. In one case each, interviews occurred at the participant's place of employment, the Public Archives of Nova Scotia, and the School for Resource and Environmental Studies at Dalhousie University. All interviews were audio-recorded with the permission of the participant, and written notes were also taken. Transcription of both tapes and written notes occurred as soon as possible following each interview.

3.1.2 Written Records

Between July 2003 and July 2004, an extensive exploration was conducted for historical, archival and contemporary documents, which provide an indication, anecdotal or scientific, of the status of diadromous fishes in the ARW and potential human-induced stresses. The aim was to identify and explore all the locations and sources that could have potentially contained relevant information (Table 5). However, it is possible that a few more obscure locations and sources were missed. Moreover, it was not possible to access a few potentially relevant government records at the National Archives of Canada, which were subject to review under the *Access to Information Act*, since the review process could not be conducted within the time constraints of the research. Relevant government, academic (biologists and historians) and non-government organization (e.g. Atlantic salmon federation, Trout Unlimited) professionals were consulted for suggestions of possible avenues for locating information.

Table 5: Major Locations and Types of Sources Explored*

Locations	Sources
• University libraries and archives in Nova Scotia • Public Archives of Nova Scotia, Halifax, NS • National Archives of Canada, Ottawa, ON • Nova Scotia Museum of Natural History library and records (see museum collections) • Fisheries Museum of the Atlantic, Lunenburg, NS • Local museums: West Hants Historical Society Museum, Windsor, NS; Avon River Heritage Society Museum, Avondale, NS • Federal, Provincial and Municipal government libraries, archives, and records: Department of Fisheries and Oceans, Nova Scotia Department of Agriculture and Fisheries, Nova Scotia Department of Natural Resources, Municipality of West Hants, and the Town of Windsor • Nova Scotia Power Inc.	• Federal Department of Fisheries Annual Reports (1867/8-1965) • Journal and Proceedings of the House of Assembly for the Province of Nova Scotia (1795-1867) • Sessional Papers of the Dominion of Canada (1867/68-1925) • Hants County Court of General Sessions of the Peace records (1796-1860) • Fishery officer reports • Published Avon River area community histories, general histories of Nova Scotia, and historic accounts • Unpublished government and non-government correspondences, petitions, memorandum, reports, studies, and other documents. • Published government and non-government reports and studies • Local fishery regulations • Local and regional newspapers • Academic journals

* This list is not exhaustive due to the large number and variety of locations and sources explored.

3.1.3 Fish Surveys

The results of recent fish survey efforts in the branches and tributaries of the lower ARW were examined in the study (Table 6). It must be noted that the failure of these efforts to detect a particular species may, especially in the case of the two 2002 surveys, reflect the time (time of year and duration of sampling), location, and methodological limitations of the studies and not necessarily absence or low abundance. NSDAF lake survey data for several upper ARW lakes were also examined. These did not reveal the presence of diadromous populations (did indicate freshwater resident brook trout and stickleback spp.), which was expected due to the existence of barriers to migration (waterfalls and power dams) into the upper ARW (see Section 4.1 and 5.1.2.5).

Table 6: Fish Sampling Efforts in the Lower Avon River Watershed

Survey	Sampling Locations	Sampling Dates	Sampling Methods
DFO Electro-fishing survey	West and Southwest branches	August 9, 2002	electro-fishing
CBCL Limited Consulting Engineers, 2003	LeBreau Creek, Fall Brook and Maple Brook (tributaries of Pesaquid Lake)	September 27 to 29, 2002	electro-fishing
Daborn *et al.*, 2004	Channels on seaward side of causeway, lower Pesaquid Lake	May 22 to July 7, 2003	gill net, fyke net
	Lower Pesaquid Lake, Allen Brook, LeBreau Creek, South Branch below power house, Sangster's Bridge, West Branch	August 7 to October 7, 2003	beach seines, ichthyoplankton tows (larval fish)

3.1.4 Fisheries Catch Data

An attempt was made to locate fishery catch data for the ARW. Despite the historical and on-going occurrence of recreational fishing activities for diadromous and freshwater species in the ARW, the only catch data (recreational creel census conducted by NSDAF) that could be located were for brook trout for the years 1986 to 1993 (ASE Consultants Inc., 1995). These data could include sea-trout and therefore were included in this study. There are no records of commercial fishery activities in the ARW.

3.1.5 Museum of Natural History Specimen Collections

The Museum of Natural History's specimen collection database was accessed to determine if it contained any diadromous fish obtained from the ARW. The collection contained a few freshwater fish specimens; however, there are no records of diadromous species.

3.2 Data Synthesis

An attempt was made to characterize each of the species known to occur in the BoF. Information from all sources was organized by species. By integrating the information obtained from all sources, a separate qualitative characterization of each diadromous species in the ARW was developed, with emphasis on presence/absence, relative abundance, location observed in the ARW, and evidence of spawning (anadromous species). Where possible, information was presented in chronological order to illustrate changes through time. Although the emphasis of this study was on European settlement to the present, a brief description of conditions prior to this period was provided. Personal biases (either consciously or unintentionally), interpretations based on limited understanding, and memory loss (in case of oral sources) can cause inaccuracies in anecdotal sources (Steedman *et al*., 1996; Mackinson and Nottestad, 1998; Neis *et al*., 1999; Johannes, 2000). The use of multiple and interdisciplinary sources can help validate the data and identify areas of uncertainty (Steedman *et al*., 1996; White and Walker, 1997; Preikshot, 1998). Since there was no direct means to assess the validity of each of the sources, information was included in the study unless it was obvious conjecture or conflicted with other comments made by the same source. Inconsistencies between sources were presented and gaps and uncertainties in information were noted.

The major human-induced stresses in the ARW and estuary were identified from the sources and expert (KIs and others consulted) opinions. Although not a major focus of this thesis, natural factors and marine human-induced threats were also briefly examined. The potential impacts of each identified threat on diadromous populations were examined based on any direct observations presented by anecdotal sources, expert opinions and knowledge, and relevant scientific literature. However, the contributions of individual factors to specific fish population, habitat, or other ecological changes are often difficult to unravel, especially in historical studies (Kelso *et al*., 1996; Steedman *et al*., 1996; Pesch and Garber, 2001). Therefore, it was generally not possible in this study to establish definitive correlations between a specific threat and specific changes experienced by fish populations. Several of the factors that complicate the identification of specific cause and effect relationships in this study include: 1) the patchy and anecdotal nature of historical information (Steedman *et al*., 1996); 2) cumulative and synergistic effects (Kelso *et al*., 1996; Steedman *et al*., 1996); 3) time delays between a specific cause and effect (fish population responses to specific stresses may take long periods before becoming apparent) (Kelso *et al*., 1996); and 4) the temporary masking of changes in fish populations by measures, such as stocking, intended to maintain fishing opportunities, and technological advances in fishing gear that increase the proportion of the fish stock harvested per unit effort even as populations decline (Post *et al*., 2002).

3.3 Ethical Considerations

Due to the key informant interview phase, the study required approval by the Dalhousie University Social Sciences and Humanities Human Research Ethics Board, which was received prior to the commencement of the interview period. KIs were asked to read and sign a consent form before the interviews began. The form clearly explained the purpose of the research and the nature of the KIs participation, including their rights to withdraw from the study at any time and to refuse to answer any questions. To ensure anonymity in regard to local anecdotal knowledge, each KI is referred to in the thesis by a number, and background information, quotes or narratives that could potentially lead to a participant's identification are not included. However, to provide proper acknowledgement for information and opinions of a purely professional/scientific nature, expert KIs and other professionals consulted are cited by name. Only the researcher had access to the names of the KIs.

Chapter 4: Diadromous Fish in the Avon River Watershed

This chapter presents a compilation of the historic and contemporary information obtained on the presence and relative abundance of diadromous species in the ARW from pre-European settlement to the present.

4.1 Habitat

Diadromous fish were identified in the rivers, streams and lakes throughout the lower ARW. Prior to human-induced obstructions to fish passage (i.e. dams) (see Chapter 5), much of the freshwater habitat in the watershed (entire upper ARW) was naturally inaccessible to anadromous species due to the high natural waterfalls on the South (15 meters) and Southwest (12 meters) branches (Government of Nova Scotia, 1816; Venning, 1869; Butler, 1894; Prince, 1910; Black, 1911; Found, 1911; Hockin, 1911; Bruce, 1918). In 1869, the fishery officer for Nova Scotia commented that:

> the Avon is the most important [river in the vicinity] and takes its rise in the Avon Lake which is of considerable size and part of which extends into the County of Lunenburg; in its descent it passes through several smaller lakes and considerable tracts of intervale land and I am informed there are fine spawning grounds at various places along the river, but unfortunately a natural fall, some three miles above the head of the tide, of some fifty feet high effectually prevent the ascent of a single fish, but it could be overcome by the expenditure of a few hundred dollars (Rogers cited in Venning, 1869, p.27).

Sources describe the South Branch above the waterfall as having exhibited excellent habitat conditions, especially for salmon (Government of Nova Scotia, 1816; Venning, 1869; Butler, 1894; Prince, 1910; Black, 1911; Found, 1911; Hockin, 1911; Bruce, 1918). From the early 1800s until the construction of hydro power dams on the South Branch in the 1920s, there was considerable local and government interest in lowering or putting a fish-way in the falls to increase the habitat available to migratory fish and thereby increase the fish production potential of the system (Government of Nova Scotia, 1816; Venning, 1869; Butler, 1894; Prince, 1910; Black, 1911; Found, 1911; Hockin, 1911; Bruce, 1918). However, it appears that no action was ever taken. Subsequently, a hydro power dam without a fish-way was built at the falls in the early 1920s (Shanks, 1994). Eels have the ability to travel over land when the ground is wet; therefore, it is not unusual to find them in isolated bodies of water (Towers, 1995). Moreover, juvenile eels may also be capable of climbing barriers such as natural falls and dam faces (McDowall, 1988). These abilities might explain how, according to local KIs, some eels have been able to access the lakes in the upper South Branch.

The exact locations of spawning, rearing, feeding, and over-wintering (salmon and striped bass) habitat in the lower ARW are species dependant, and the specific areas utilized would have undoubtedly changed over time as a result of natural and human-induced habitat alterations and accessibility restrictions. The identification of and description of changes in key habitat areas for each species were beyond the scope of this thesis. However, the tributaries of the West Branch and the pools near the head of tide on the West and South branches have been identified by sources as, at least historically, areas frequented by anadromous species. These areas may provide or have provided spawning, rearing or other key habitat.

4.2 Status of Diadromous Fish

4.2.1 General Status of Fish prior to the Early 19th Century

Archaeological evidence has been found of human (Mi'kmaq) habitations in the Minas Basin region as early as 2500 years BP (Deal and Butt, 1990; Nash and Stewart, 1990). The primary food source of the Mi'kmaq was fish, especially the spring and fall runs of diadromous species such as salmon, smelt, sturgeon, gaspereau, and eels (Deal and Butt, 1990; Nash and Stewart, 1990; Miller, 1993). Summer villages were established in areas in proximity to abundant fish resources such as the mouths and heads of tide of tidal rivers (Miller, 1993). Although it is unknown to what extent, if any, pre-colonial Mi'kmaq exploited the fish resources in the Avon River, which they called the Pesegitk' ('where the tide divides and flows up in a fork' [Rand, 1875]), there is evidence that Mi'kmaq had campsites in the vicinity (Deal and Butt, 1990; KI#3, 10, 25). For example, according to KI#3, 10, and 25, a summer encampment (date unknown) was known to exist on the South Branch around the head of tide (Indian Orchard). The presence of these camps suggests that fish resources were abundant in the watershed prior to European settlement.

The increase in fishing pressures and habitat alterations (e.g. dyking) following European settlement in 1685 would have impacted fish populations, although the nature and extent of the effects are unknown (see Chapter 5). Pressures on fish from human activities would have intensified as the human population grew throughout the 18th and into the 19th century. However, records expressing concern over the status of fish did not begin to manifest until the 1820s. The earliest reference found was an 1823 record of the Court of General Sessions of the Peace for Hants County (1812-1849), in which concern was expressed over the impacts of a mill-dam and fishing pressure (placing nets across the river) on migratory fish (fishery) on the South Branch. That such concerns were being raised in the early 1800s may indicate that some decline in fish abundance was being observed.

4.2.2 Atlantic Salmon

Sources suggest that there were probably both spring and fall runs of Atlantic salmon (*Salmo salar*) in the ARW (Department of Marine and Fisheries [DMF], 1879; Deemer and Skelhorn, 1983; KI#16, 28). Additionally, it was common for fall-run salmon to over-winter in the ARW and descend after the ice melt in early spring (Gilpin, 1879; KI#16). Although salmon are believed to have been found throughout the lower ARW, there were no reliable accounts found of salmon in the upper ARW. However, records indicate that the DMF stocked salmon in the Avon River from 1877 until the 1930s. Although exact locations were not specified, some fish may have been placed in the upper watershed.

In 1986, Conrad and Semple (1987) conducted an assessment, based on physical stream characteristics (water depth, streamflow, stream bottom and substrate), of the quality and quantity of Atlantic salmon habitat (spawning and rearing) available on the West and lower Southwest (below the falls) branches. Based on this habitat assessment, Conrad and Semple (1987) estimated that these branches had the potential of producing 5000 smolts and between 400 and 500 adult salmon annually, assuming the species was able to freely access these areas to spawn (which does not appear to have been the case after construction of the causeway in 1970). Since there have been no quantitative surveys of salmon abundance, it is uncertain to what extent this theoretical estimate reflects actual pre- or post-causeway salmon production. Moreover, it should be noted that other physical, chemical, and biological variables (e.g. water quality, temperature, riparian and in-stream vegetation cover), which were not included in the assessment, also influence habitat quality and productivity. Since habitat surveys have not been previously conducted, it is uncertain to what extent the 1986 survey reflects historic habitat conditions. Similarly, to date, no follow-up study has been performed to estimate the extent to which the habitat has been subsequently degraded or improved.

The earliest references to fish in the ARW were regarding the importance of the salmon fishery in the late 17th and 18th centuries. According to Dunfield (1985), the Acadians considered the Avon (Pisiquid) River as one of the most important salmon rivers in Nova Scotia, suggesting a high abundance of the species compared with other rivers at the time. Salmon were so plentiful in the summer months and the fishery for that species so well known that by the late 18th century the English settlers commonly referred to the Avon River as the "Salmon River", and it was, reportedly, often labelled as such on charts of the time (Public Archives of Nova Scotia, 1933).

By the mid-1800s, salmon were still relatively abundant. Perley (1852, p.158) observed that "salmon ascend the Avon, and its tributaries, in considerable numbers", and the South Branch was still considered "one of the finest salmon rivers in the province" (Butler, 1894). However, the inclusion of specific provisions in the *Hants' County Fishery Regulations, for 1843,* "in order to preserve the Salmon Fishery of the River St. Croix, and South and West branch of the Avon", suggests that the population was in need of protection in both branches and thus some level of decline was likely being observed.

Sources indicate that sometime thereafter the salmon population experienced a considerable downturn. According to Venning (1869) and McDougall (1898), salmon and other anadromous species had almost disappeared from the watershed around the 1860s. Further, fishery officers reported that in 1878, 1879 and 1880 respectively, salmon in the Avon River were "scarce and small" (Burnham quoted in DMF, 1879, p.239), were "never known so scarce" (DMF, 1880, p.219), and had "almost wholly disappeared" (Rogers, 1881, p.154).

By the late 1880s, salmon numbers had improved (Wilmot, 1887). By the turn of the century, salmon were again reported as being plentiful (McDougall, 1898; Hockin, 1901) and continued to be abundant in the ARW into the early 20th century (Smith, 1965;

Cunningham, 1909; Rodd, 1916; KI#6, 7, 10, 16, 25). For example, a pond on the South Branch was considered “one of the best salmon fishing holes in Nova Scotia” (KI#6).

However, by the mid-1900s, the population appeared to have reduced much below historic abundances (Smith, 1965; KI#6, 7, 9, 10, 11, 16, 25, 28), and the Avon was no longer considered a prime salmon river (MacEachern, 1968; Deemer and Skelhorn, 1983). Many sources commented that the decline began in the late 1920s/30s, possibly a result of the alteration and diversion of water flows (and thus degradation or loss of habitat) from hydro power development (Smith, 1965; KI#6, 7, 9, 10, 11, 25).

Sources conflict as to the condition of the population in the ARW at the time of the causeway’s construction. Beginning in 1965 (when plans for the causeway commenced), numerous DFO documents claimed that salmon runs were insignificant. In 1968, DFO (1968) and Lucas (1968) claimed that no salmon had been reported on the South Branch in recent years. Conversely, a 1965 DFO study reported that small runs existed on the South Branch below the power dam and on the West Branch (Smith, 1965). Nevertheless, the 1965 study asserted that, by the mid-1960s, very few salmon still utilized the ARW, especially the West Branch, whose run had been reduced (since the installation of the West Branch diversion dam) to “almost the point of non-existence”. It estimated that runs in the ARW were not likely to exceed 50 salmon and grilse annually. However, it is uncertain how this number was reached, and it is much lower than Conrad and Semple (1986)’s subsequent estimate based on the production potential of the West and Southwest branches.

In contrast to the DFO accounts, reports of KIs and other local residents and fishers indicate that, despite the decline, fair numbers of salmon still frequented the ARW prior to causeway construction (MacEachern, 1968; Letters to DFO from Concerned Citizens, 1987; KI#3, 7, 9, 10, 11, 16, 19, 22, 25, 28). For example, KI#10 commented that “if you knew where to look for them, there were all kinds of them”, and MacEachern (1968) reported that, in the late 1960s, two local fishers alone had caught 70 salmon (mostly grilse) in just one season.

Evidence from local citizens suggests that the salmon population drastically declined in the decade following the construction of the causeway. According to the majority of sources, the species seemed to have disappeared from the ARW immediately upon or within a few years of the causeway's construction (Letters to DFO from Concerned Citizens, 1987; KI# 3, 7, 9, 10, 11, 14, 19, 25) (Table 7). Conversely, although much below mid-1900 abundances, KI#28 claimed to have seen evidence of a spawning run (salmon and small fry) until the early 1980s. Additionally, in a 1983 letter to the DFO, two local fishers stated that spring and fall runs of salmon still ascended the South Branch, where they were often fished illegally (Deemer and Skelhorn, 1983). Only one other account was found of salmon above the causeway. In spring 1986, one local fisher reported a few salmon in LeBreau Creek (a tributary of Pesaquid Lake), when the causeway gates were open for several weeks for the annual maintenance period in May (Letters to DFO from Concerned Citizens, 1987). However, this was the first time that he had observed the species in the ARW in many years.

Table 7: Selected Comments by Key Informants on the Presence of Salmon in the Avon River Watershed After 1970

KI#	Comment
3	After the causeway was built, I haven't seen any salmon above it (*paraphrased*)
7	"After the power dams you'd seen some; but once they put the causeway in, that was the end"
9	In early 1970s, people were still catching sea-run salmon in Allen Brook and the West Branch. The last salmon was caught in 1973 (*paraphrased*).
10	"After the causeway was in, there was no…salmon"
11	"But when they put the causeway in, the salmon stopped"
14	"Seems that once they put the causeway in, whether it was that or pollution or something else, at that point the fishing just stopped"
19	"When they put the causeway in, you didn't see any salmon"
25	"But in the Avon they haven't caught salmon, I don't think, since after the causeway went in… I haven't heard of anyone catching salmon since the causeway has been in"

No evidence of a salmon population in the ARW after the 1980s could be located. KIs reported not to have observed or heard of salmon, at least since that time, and believe that the species had disappeared. However, due to the ban on iBoF salmon harvesting since 1990, it is possible that some fishers may have simply been reluctant to admit to having caught them. Scientific survey efforts in August 2002 (DFO Electro-fishing Database), September 2002 (CBCL Limited Consulting Engineers [CBCL], 2003), and late May to October 2003 (Daborn *et al.*, 2004) have also failed to detect any adult or juvenile salmon, even though they were conducted when salmon would have been expected to be present (adults in the spring and/or fall, and juveniles throughout the year). No other records of salmon could be located. Although it appears that the salmon population has been extirpated, it is remotely possible that it persists at an extremely low abundance.

4.2.3 Gaspereau (Alewife and Blueback Herring)

The gaspereau population in the ARW is composed of alewives (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), alewives currently being more numerous than blueback herring (Daborn *et al*., 2004). Since historic records and KIs only referred to gaspereau in general and thus made no distinction between the two species, it is uncertain whether the current relative proportions of these species reflect historic conditions.

Spawning runs of both species occur in May and early June and seaward migration of YOY occurs mostly in September (Daborn *et al*., 2004). Both species have been found throughout the branches and streams of the lower ARW. Blueback herring spawn in rivers, whereas alewives prefer lakes and pools for spawning and rearing (Scott and Crossman, 1973; Halliwell *et al*., 1998; Coker *et al*., 2001). Currently, it appears that Pesaquid Lake, which formed as a result of the construction of the causeway in 1970, provides the most significant area of potential spawning and rearing habitat for alewife (Conrad and Semple, 1987; J. Gibson, 2004; R. Bradford, 2005, pers.comm.). However, prior to hydro power development (construction of the West Branch diversion dam) in the mid-1930s, Black River Lake may have provided a substantial area of habitat for ARW alewife.

Little historical information was found specifically on the status of gaspereau in the ARW. The earliest source located was the *Hants' County Fishery Regulations, for 1843*, which highlighted "the great advantage of Gaspereaux and Alewive fishery on the South and West branch of the River Avon", suggesting that the species were relatively abundant and the fishery of local importance. Additionally, Perley (1852, p.158) observed that "great numbers of gaspereau every spring ascend the...Avon...to spawn". However, the need of regulations to protect gaspereau suggests that the species may have been in decline. The only potential indication of the status of gaspereau in the mid to late 1800s may be ascertained from Venning (1869) and McDougall (1898), which describe the drastic decline of gaspereau and other anadromous fish around the 1860s and their recovery by the end of the 19th century.

No sources were located describing the gaspereau population in the ARW in the early 1900s. However, sources indicate that, from the 1930s to 1970, small (MacEachern, 1965; Smith, 1965; KI#28) to fairly plentiful (KI#3, 7, 9, 10, 11, 19, 22) runs ascended all the branches (especially the West and South) and seemed especially plentiful in the streams and pools near the heads of tide (KI#3, 7, 22). KI#11 commented that "people would say that when they were running that would be all you would see. They had good runs in the Avon". Nevertheless, gaspereau did not appear to be as abundant in the ARW compared with other nearby rivers, namely the Kennetcook and Gaspereau Rivers (KI#3, 10). In the mid-1960s, the DFO claimed that "in recent years the runs [on the West branch] have fallen off to a level where the dip net fishery is practically nil" (Smith, 1965). However, KIs did not note any significant changes in the relative abundance prior to 1970.

Since 1970, several local residents have reported seeing large numbers of gaspereau amassed on the seaward side of the causeway every spring (KI#6, 7, 14, 16, 26). Evidence suggests that some fish have been able to migrate into the ARW in May when the gates were left open (Conrad and Semple, 1987; Letters to DFO from Concerned Citizens, 1987; Daborn *et al*., 2004; KI#3, 5, 9, 10, 11, 18, 19, 20, 21, 25, 26, 28, 29). Nevertheless, the annual runs, overall, appear to have been well below pre-causeway abundances (Letters to DFO from Concerned Citizens, 1987; KI#9, 10, 11, 18, 19, 25). However, in some years gaspereau have, reportedly, been more numerous. For example, in 1987, during the gate maintenance period, local residents reported an abundance of gaspereau in Pesaquid Lake and its tributary streams that had not been observed since prior to causeway completion (Conrad and Semple, 1987; Letters to DFO from Concerned Citizens, 1987). In 2003, Daborn *et al*. (2004) found an abundance of adult and juvenile alewives and blueback herring, primarily in Pesaquid Lake and its tributary streams and the South Branch below the power dam. According to some local residents, the run in 2003 was much larger than it had been in many prior years, possibly a result of the gate being kept open for a longer period of time (most of May) creating more favourable fish passage conditions (Daborn *et al*., 2004; KI#5, 29). Electro-fishing surveys in late August and September 2002 (CBCL, 2003; DFO Electro-fishing Database**)** failed to capture YOY of either species, which would be expected to be present until the fall. These surveys did not take place during gaspereau spawning migrations and thus adults would not have been expected.

4.2.4 Rainbow Smelt

Little historic information was located specifically on Rainbow smelt (*Osmerus mordax*) in the ARW. Perley (1852, p.159) observed that “smelts ascend all the rivers in this locality [Avon River estuary], at the close of winter, in almost miraculous abundance”. Although plentiful runs of smelt were reported in the rivers in the West Hants/Avon area in 1879 and 1880 (DMF, 1880; Rogers, 1881), Venning (1869) and McDougall (1898) asserted that anadromous species including smelt had almost disappeared from the watershed around 1860s until the 1890s.

According to KIs and other local residents, smelt were extremely plentiful in the lower ARW for much of the 20th century prior to the construction of the causeway, especially in the tidal portion and head of tide of the West Branch and in its small tributary streams (Letters to DFO from Concerned Citizens, 1987; KI#3, 9, 10, 13, 16, 18, 19, 20, 21, 28). KI#10 commented that “some of the small tributaries there, you could practically walk on them…freshwater would fill up with them and you couldn’t see the bottom”. Nevertheless, KI#3 and 13 indicated that, although plentiful, runs were generally less abundant than in the Gaspereau and Kennetcook Rivers. KIs recalled that considerable quantities of fish would be caught in an April-May recreational dip-net fishery on the West Branch and streams in the 1930s to early 1950s (KI#13, 18, 20). In 1968, the DFO claimed that only small runs of smelt ever utilized the ARW and that these had recently almost disappeared (DFO, 1968; Lucas, 1968). However, only a few years earlier, a DFO investigation asserted that there were still small runs on the West Branch (Smith, 1965). Most KIs did not indicate the occurrence of any changes in the smelt population prior to the causeway. However, KI#18 and 20 recalled that the fishery and the species had somewhat declined by the late 1950s and 1960s.

Following the construction of the causeway, there has been little indication of smelt in the ARW. Although KI#21 claimed that smelt are still fairly plentiful, the majority of sources have suggested that the species has nearly or, perhaps, entirely disappeared from the ARW. Many local residents, who were aware of numerous smelt in the past, claimed to have not observed or heard of smelt in the ARW since around the time of the causeway's construction (Letters to DFO from Concerned Citizens, 1987; KI#10, 18, 28). Several other KIs asserted that smelt runs had declined to almost nothing since the 1970s (causeway) (KI#13, 16, 19, 20, 25). However, these KIs claimed that they had, on occasion, seen or heard of a few fish in the system in recent years, primarily when the causeway gates had been kept open in May. Daborn *et al*. (2004) failed to capture any smelt in the ARW in 2003. However, they speculated that the study, which began in late May, may have started too late to detect the main spawning and downstream migrations. The timing (late summer and fall) of the 2002 electro-fishing surveys (CBCL, 2003; DFO Electro-fishing Database) did not coincide with when smelt would be expected in the river.

4.2.5 Sea-Run Brook Trout (Sea-Trout)

According to DFO documents from the 1960s, the most important recreational fishery in the Avon system was for resident brook trout (*Salvelinus fontinalis*), which were mostly taken from the lakes (DFO, 1968; Smith, 1965). Reflecting this, KIs (recreational fishers) were, in general, more familiar and concerned with the resident trout population compared with other species. Resident trout frequent the lakes, pools, and streams throughout the upper and lower ARW; however, sea-trout appear limited to the lower watershed. Since both forms intermingle while in freshwater (part of same population), information on changes in the overall brook trout population (resident and sea-trout) in the lower ARW will be briefly presented. However, the focus of the following section is on information specifically concerning sea-trout. It must be noted that the actual status of the overall brook trout population may have been masked by stocking efforts undertaken since the early 20th century and therefore the population may have been in a poorer condition than it appeared to recreational fishers.

Sea-trout were caught while angling for resident trout and other species in the branches and streams of the lower watershed. Although observed up to the falls on the South and Southwest branches (mostly prior to the 1930s) (KI#7, 9, 10, 13, 25), sea-trout were most often caught in areas below the head of tide, especially on the West Branch and its small tributary streams (Smith, 1965; KI#7, 9, 18, 19, 25, 28). Allen Brook, a tributary of the South Branch/Pesaquid Lake, was described as an especially good place to find sea-trout (historically and presently) (KI#9, 25, 29). Sea-trout were predominantly caught in the spring (~May) (Smith, 1965; KI#9, 10, 25, 28), probably prior to or during spring seaward feeding migrations.

Only two sources were found specifically mentioning sea-trout in the ARW prior to the 20th century. Butler (1894) commented that the passage of sea-trout up the South and West branches was almost totally obstructed by dams, and McDougall (1898) described the considerable decline of sea-trout (and other anadromous fish) from the river and its recovery at the end of the 19th century. In the 20th century, KIs described a gradual decline in the overall trout population from historic abundances and a concurrent decrease in the average size of trout. According to KI#9, 10 and 19, there were good numbers of resident and sea-trout throughout the lower ARW prior to the 1930s. KI#7, 9 and 10 commented that following hydro-power development on the South and West branches, the numbers of trout in all three branches began to diminish. However, trout were still productive in the watershed in the 1940s, 1950s, and 1960s, with good numbers of sea-trout being caught (KI#3, 7, 9, 10, 13, 18, 20, 21). According to Smith (1965), small sea-trout runs were reported on the West Branch and a few fish would be caught in May. In the late 1950s and 1960s, KI#20 noticed that it was becoming more difficult to catch trout, especially of a larger size. Although KIs are still aware of the presence of a few sea-trout in lower ARW in the spring, the numbers observed declined considerably following the construction of the causeway (KI#7, 9, 10, 13, 24, 25). Additionally, KIs have noticed significant declines in the overall trout population since the late 1970s and 1980s (KI#12, 24, 26). However, KI#9 and 10 commented that sea-trout had been slightly more plentiful in the few years prior to 2004.

Recent sampling survey efforts (2002, 2003) have failed to capture any sea-trout in the lower ARW or estuary. Sampling efforts by Daborn *et al*. (2004) may have begun too late (late May) to detect downstream feeding migrations; however, all three surveys (CBCL, 2003; Daborn *et al*., 2004; DFO Electro-fishing Database) coincided with the period when sea-trout would be expected to be undertaking upstream spawning migrations (late summer and fall). Recreational creel survey data for brook trout (which may include sea-trout) in the ARW for 1986-1993 is provided in Table 8. According to these data, only a small number of fish were caught in total during the eight years, with zero being caught in four of the years. Catch per time spent fishing (catch per unit effort) was less than 1.0 in all of the four years that trout were caught. These data could suggest that trout were not plentiful during the late 1980s/early 1990s. However, creel surveys do not necessarily provide an accurate representation of fishing effort (number of anglers and hours fished) or numbers caught since the quality of the data is dependent on the thoroughness of the survey efforts, which may have been quite limited (ASE Consultants Inc., 1995).

Table 8: Recreational Catch Data for Brook Trout in the Avon River Watershed, Based on Creel Surveys

Year	# Caught	% Released	# Anglers	Total Time Spent Fishing (Hours)	Catch/Time Spent Fishing
1986	123	1.6	101	133.3	0.92
1987	0	-	60	74.4	0.00
1988	0	-	28	33.8	0.00
1989	0	-	9	5.8	0.00
1990	7	0.0	28	62.4	0.11
1991	20	35.0	31	42.7	0.47
1992	0	-	8	7.5	0.00
1993	4	0.0	12	12.9	0.31

Source: ASE Consultants Inc., 1995

4.2.6 American Eel

Although there are no historic records on American eel (*Anguilla rostrata*), KIs asserted that the species has always frequented the freshwater lakes, streams and rivers throughout the ARW (KI#1, 7, 11, 12, 10, 13, 18, 19, 20, 21, 24, 25, 26, 28). The lack of records likely reflects this species' unpopularity as a commercial or sport fish. Although much more prevalent in the lower ARW, some KIs reported eels on the upper South Branch, specifically the lakes (Falls, Mochingigh, and Zwicker) directly above the power dams (KI#12, 13, 25, 28). KI#28 had also seen them in the South Branch headwaters (Card Lake). From their earlier experiences (1930s, 40s and 50s) to the present, KIs described the species as being plentiful (KI#7, 11, 12, 10, 18, 19, 20, 21, 24, 25, 26, 28).

KI#10 stated that "the water was infested with eels" (1930s and 1940s) and KI#18 that "we would catch eels along the banks. There were eels everywhere. They were very plentiful" (in the1950s and 1960s). Although KIs agree that there still appears to be many eels utilizing the system, they differ on what, if any, changes have occurred in population size. KI#7, 11, 25 and 28 asserted that there are noticeably fewer eels, at least in some areas, now as compared to a couple of decades ago (KI#11 and 28 started noticing declines in the early 1980s, and KI#7 and 25 in the early 1990s). Conversely, KI#19 and 24 believe that eels had increased over the same period of time. Still, KI#21 and 25 claimed there have not been any noticeable changes. A small number of eels were captured in recent survey efforts: three were captured on the Southwest Branch in Late August 2002 (DFO Electro-fishing Database), nine in Fall Brook in late September 2002 (CBCL, 2003), and 13 in Pesaquid Lake in May-June 2003 (Daborn *et al*., 2004).

4.2.7 American Shad

Although there are numerous records of American shad (*Alosa sapidissima*) frequenting (being fished in) the Avon estuary, mainly during the summer months (late June to late August or September), from the mid-1800s to the present (Perley, 1852; DMF, 1879; Hockin, 1897; Rogers, 1886; KI#7, 8, 16, 25, 26), the data are inconclusive regarding whether the species ever migrated into the ARW to spawn. Perley (1852) claimed that although shad from non-local populations entered the Avon estuary in the summer to feed, especially on shrimp which were abundant in the mud-flats, "the spring shad [spawning] do not go up the Avon [River] to spawn" (p.158). Moreover, the majority of KIs were not aware of the presence, historic or contemporary, of shad in the ARW. Scientific survey efforts in 2002 and 2003 did not detect any shad in the ARW (CBCL, 2003; Daborn *et al*., 2004; DFO Electro-fishing Database). Spawning generally occurs in May and June (Leim, 1924; Williams and Daborn, 1984) and juvenile downstream migrations begin in the late summer and fall (Scott and Scott, 1988; Stokesbury and Dadswell, 1989). Therefore, if a spawning population exists, the Daborn *et al*. (2004) study would have begun in time to detect the latter part of the spawning migration, and juveniles would have been expected in the river when all three sampling efforts were being conducted. Several local fishers claimed to have observed the occasional fish with spawn in the estuary (reported in Prince, 1910; KI#16). However, since a historic spawning run is known to have existed on the Kennetcook River (and may still) (Chaput and Bradford, 2003) and could have existed on the other tributary systems, the presence of spawn shad in the estuary does not confirm the existence of an ARW spawning population.

Nevertheless, there are several sources that provide some support for the existence of a spawning population of shad in the ARW prior to the 1960s or 1970s. KI#7 claimed to have fished for shad in the spring in the ARW prior to 1970, and KI#11 had heard that a good-sized run used to be found on the West Branch. Both KIs asserted that the ARW shad run persisted until the construction of the causeway, at which time the species quickly disappeared from the watershed. In addition, the Dominion Shad Fishery Commission (which was established to gather information from fishers on status of shad in Atlantic Canada in response to a drastic decline in the species throughout the region) implied that a limited run existed and recommended that the Avon River above a line drawn from Avondale to Falmouth be designated a reserve for the propagation of fish (Prince, 1910). Leim (1924) also suggested that shad spawned in low numbers. However, the evidence for the two previous documents' conclusions was not apparent. In a letter to the Deputy Minister of Marine and Fisheries, Black (1911) stated that shad frequented the South Branch below the falls. More recent DFO documents also asserted that small runs had been reported in the past (DFO, 1968; Lucas, 1968; Smith, 1965). However, contrary to KI#7 and 11, these claimed that shad had almost disappeared prior to 1970. Moreover, a recent government status assessment of shad in Atlantic Canada acknowledged the possibility of a historic ARW spawning population, although it could not verify its existence (Chaput and Bradford, 2003).

4.2.8 Striped Bass

There are many records of striped bass (*Morone saxatilis*) frequenting (and being fished in) the Avon estuary (Perley, 1852; KI#4, 7, 8, 9, 11, 14, 16, 18, 24, 25, 26, 29). The majority of KIs were not aware of striped bass ever entering the ARW, and no documented sources were located to suggest their historic or current presence. KI#7, 9, 18, and 25 were the only sources to suggest the presence of the species in the ARW, although these KIs also indicated that the species was never known to be prevalent in the watershed. KI#7 had heard that there was a historic fall upstream migration, which had disappeared, at least at the time of the causeway, but perhaps earlier. KI#9, 18, and 25 were only aware of striped bass in the spring/summer. KI#9 reported to have caught a few fish near the head of tide in the spring/summer on the West Branch in the late 1960s. Following the construction of the causeway, this KI asserted that the species would occasionally enter Pesaquid Lake in the spring, but had not observed or heard of any in the past decade. However, KI#18 and 25 suggested that the species continues to enter Pesaquid Lake in the spring, although neither had personally observed the fish. KI#18 reported that a relative had claimed to have caught one small fish off Sangster's Bridge (upper Pesaquid Lake) in early spring 2004, and KI#25 had heard of people catching the species in lower Pesaquid Lake in the spring (mostly directly above the causeway) in recent years. None of the KIs had been aware of striped bass above Pesaquid Lake after 1970.

Daborn *et al*. (2004) collected immature bass in the channels on the seaward side of the causeway from mid-June to late July (majority in late June and July); however, no adults or YOY were obtained in sampling efforts undertaken above the structure from late May to October. The timing of this study should have corresponded with upstream spawning (April to June) and possibly over-wintering (late fall) migrations, if they existed. Other scientific surveys undertaken in late August and September 2002 in areas of the lower ARW also failed to capture striped bass (CBCL, 2003; DFO Electro-fishing Database); however, due to their timing and other limitations, this is not unexpected.

Although striped bass may have entered the ARW, there is no evidence of spawning; however, the absence of direct evidence does not necessarily refute the possibility. The limited evidence of the species in the ARW suggests that, if indeed they are or were ever present, they were likely individuals of non-local origin. Since only two KIs reported them above the causeway, further research will be needed to confirm that striped bass currently enter Pesaquid Lake, and, if so, to determine whether these individuals represent a spawning population. None of the bass collected by Daborn *et al*. (2004) in the channels directly below the causeway were in spawning condition. Moreover, these fish were captured in the summer when non-local fish enter rivers and estuaries while on coastal feeding migrations. Furthermore, the fish in the estuary might also belong to a local tributary population (e.g. Kennetcook and/or St. Croix River). Even if one does not currently exist, a historic spawning population is possible; however, the complete absence of records and the low level of local knowledge of the species may suggest otherwise. It is also possible that native (if a spawning population existed) and/or non-local fish could have used the ARW for over-wintering, at least historically. KI#7's assertion of a historic fall upstream migration (when over-wintering migrations occur) may suggest such an activity. The absence of direct records and other local knowledge of such an activity (i.e. presence in winter) may be a result of an observation/sampling bias against the winter season, when fishing activity in the ARW, if any, would be minimal. If the ARW does, or did in the past, provide over-wintering habitat, the fish that were reported in the ARW in the spring might also be non-local fish on their migration from over-wintering grounds back to the sea.

4.2.9 Atlantic Sturgeon

Although sources indicate that Atlantic sturgeon (*Acipenser oxyrynchus*) (often quite large-sized individuals) frequented the Avon estuary, the present study was unable to uncover evidence of a spawning population in the ARW. The only early historic reference to sturgeon in the estuary was by Perley (1852) who reported the catch of 'very large' individuals. According to A. Evans cited in Percy (1997), some local fishers claimed that sturgeon were abundant (and often large-sized) in the estuary in the early to mid-1980s, but had disappeared by the mid-1990s. However, several KIs asserted to have observed, caught or heard of large sturgeon in the estuary since that time, although they were uncertain as to abundance (KI#9, 16, 22, 25, 26). Historic or recent records of sturgeon entering the ARW were not located, nor did any KI confirm having observed or heard of any in the system. However, several KIs believe the species may have entered the ARW prior to the causeway (KI#9, 22, 24, 25). Additionally, none of the sources identified the presence of ripe females, spent adults or juveniles in the Avon estuary, which might have been indicative of the presence of a spawning population (in at least one of the tributaries).

4.2.10 Atlantic Tomcod

Atlantic tomcod (*Microgadus tomcod*) were described as abundant in the Avon estuary in the early to mid-1900s and were commonly fished in the estuary for recreation (rarely consumed) or for use as bait (KI#7, 8, 13, 16): “They were in here by the truck load, by the thousands. You could catch a couple of buckets full in a day” (KI#7). Most KIs had insufficient knowledge on the species to comment on changes in population size over time in the estuary; however, KI #8 suggested that by the late 1950s it had become increasingly difficult to catch tomcod. Nevertheless, the species is still described as common in the estuary (KI#16, 25, 26). Daborn *et al*. (2004) collected only three tomcod, all on the seaward side of the causeway, one each in late May, mid-June, and late July.

Despite the species’ presence in the estuary, there was no evidence located to confirm the existence of a historic or current spawning population in the ARW. It is possible that the tomcod in the estuary spawn in another tributary system (e.g. Kennetcook and/or St. Croix River). Only two sources (KIs) reported being aware of tomcod in the ARW. Before the causeway, KI#20 and 21 had observed the occasional tomcod in the spring and summer in the lower tidal portion of the ARW (around Sangster’s Bridge) when the tide came in. Since tomcod spawn in the winter, these observations do not provide support for the existence of a historic ARW spawning population. These KIs did not report observing the species in the ARW after the causeway’s construction. The failure to find historic or contemporary records of a spawning population in the ARW may simply reflect the time of year that tomcod spawn rather than its absence, since winter fishing activities, if any, were not common in the ARW, nor were any scientific surveys conducted during this time.

4.2.11 Sea Lamprey

There is no documented historic or contemporary evidence of sea lamprey (*Petromyzon marinus*) in the ARW, and KIs were unaware of their presence. However, in a survey conducted by Beamish (1980), fishery officers reported the presence of spawning-size fish on the Kennetcook River, which suggests the existence of a spawning population in that system. That fishery officers had identified spawning-size fish on the

Kennetcook River and not the Avon suggests that the latter may not support a spawning population.

4.2.12 Other Facultatively Anadromous Species

No historic documentation was found on the facultatively anadromous white perch or three stickleback species (*Gasterosteus aculeatus, Apeltes quadracus,* and *Pungitius pungitius*) in the ARW. Although many KIs were aware of yellow perch (*Perca flavescens*) (an unrelated purely freshwater species) in the ARW (KI#9, 19, 20, 21, 24, 25, 26), only KI#12 and 28 were able to positively identify white perch. The latter two KIs suggested the fish are locally abundant in certain areas. Neither KI was aware of anadromy in the population or had noticed any significant changes in the population size. Daborn *et al*. (2004) collected white perch on both sides of the causeway: five were caught in the channel directly below the causeway, and numerous, mostly YOY, in Pesaquid Lake. Although the presence of individuals in the estuary below the causeway could suggest some degree of anadromy, this was the only indication of such an activity in the population and it is possible that those individuals belonged to a local tributary watershed population such as the Kennetcook or St. Croix River. Therefore, it is distinctly possible that the ARW white perch are not anadromous and remain entirely within freshwater.

Specimens of all three stickleback species were collected by Daborn *et al*. (2004) in the lower ARW, mostly in LeBreau Creek and Allen Brook. A few local KIs (#11, 12, 20, 25, 28) had mentioned the presence of sticklebacks, but could not distinguish the species or comment on changes in relative abundance. There was no evidence of anadromy in the stickleback populations in the lower ARW, although it may be possible. The absence of documentation and local knowledge of white perch and stickleback spp. is likely a symptom of their lack of value as commercial or sport fish.

4.3 Summary

Evidence was located to support the historic and/or contemporary presence of nine diadromous species in the ARW, eight are anadromous and one, the American eel, is catadromous (Table 9). Although it appears that sturgeon and sea lamprey have visited the Avon estuary, there is no indication of the historic or recent presence of either species in the ARW. The existence of anadromy and trends in relative abundances in the ARW white perch and stickleback populations could not be determined from this study due to the limited information available on these species. Of the eight anadromous species in the ARW, the findings are only able to confirm the existence of historic spawning populations of salmon, alewife, blueback herring, smelt, and sea-trout. The study did find some evidence to suggest that there may have been a historic spawning population of shad; however, the data are insufficient to confirm the existence of such a population. There is no evidence to suggest that striped bass, which had been identified in the ARW by a few KIs, ever utilized the watershed for spawning purposes. However, as suggested by KI#7's claim that this species historically migrated upstream in the fall, it is possible that the lower ARW may have served as over-wintering habitat for local (if they spawned) and/or non-local striped bass. It is not inconceivable that a tomcod spawning population may have historically gone and/or continues to go unnoticed in the ARW due to the lack of fishing and sampling effort during the winter, when spawning of this species would occur.

Table 9: Historic and Current Status and Characteristics of Diadromous Fish Species in Avon River Watershed

Species	Historic Presence[1]	Evidence of Spawning Stock[2]	Current Status[3]
Atlantic Salmon	P	Y	N
Gaspereau	P	Y	D
Smelt	P	Y	SD
Sea-trout	P	Y	D
Shad	P	I	N
Striped bass	P	N	EP
Eel	P	N/A	EP
Sea lamprey	N	N	N
Atlantic Sturgeon	N	N	N
Tomcod	P	N	N

[1] *P*-present; *N*-no records of presence

[2] *Y*-spawning stock; *N*-no indication of spawning; *N/A*-not applicable; *I*-inconclusive

[3] *D*-declined from historic abundance; *SD*-significantly declined from historic abundance; *EP*-evidence of presence, but status unknown; *N*-no records of presence in recent years

Since historical information tends to primarily concern fish species of particular commercial or recreational value (Steedman *et al*., 1996), the fact that this study could not uncover conclusive evidence of spawning runs of tomcod, sturgeon, and sea lamprey does not necessarily signify their absence. Nevertheless, it is possible that the shad, striped bass, tomcod, and sturgeon which have been observed in the ARW and/or estuary may have simply been migrants from other river populations (Canadian and American), which had entered the Avon River to feed. Alternatively, these fish could have belonged to populations on one or more of the tributary river systems emptying into the Avon estuary (e.g. Kennetcook or St. Croix River). Although there is some evidence of shad runs on the Kennetcook River (Chaput and Bradford, 2003), like the ARW, the existence of runs on the other tributary systems is uncertain.

Despite the limited amount of information on fish prior to the mid-1800s, it appears probable, based on later data, that the ARW supported fairly productive populations of, at least, salmon, alewife, blueback herring, eels, smelt, sea-trout, and perhaps shad. By the late 1860s, noticeable declines of anadromous populations (specifically, salmon, smelt, sea-trout, and gaspereau) had manifested. These populations apparently experienced a brief period of recovery between the late 1800s and early 1900s. Due to the limited information located from that time period, it is uncertain to what extent relative abundances reflected historic conditions; however, salmon were again being reported as plentiful. Several sources assert that anadromous populations, particularly salmon, began declining sometime following hydro power development on the South and West branches in the 1920s/30s. Due to discrepancies between sources, the extent to which anadromous population abundances changed in the decades leading up to the Windsor Causeway's construction could not be ascertained. DFO documents from the 1960s, assert that anadromous runs (salmon, sea-trout, smelt, gaspereau, and shad) had significantly declined by the mid-1960s. Conversely, KIs and other local sources generally assert that, despite some declines (particularly in salmon and trout), fairly good anadromous runs persisted until the time of the causeway's construction.

The most significant changes to the ARW diadromous fish community have occurred in the last 35 years. Since 1970, all known anadromous fish populations in the ARW have declined. Most of these changes began to manifest immediately upon or within a few years of the causeway’s completion. The most pronounced changes have been observed in smelt and salmon; the former appears to have deteriorated to extremely low abundances, and the latter, which has not been reported in the ARW since the late 1980s, has probably become extirpated. Moreover, there has been no indication of shad, whether representing a spawning run or migrants of non-local origin, in the ARW since the completion of the causeway. Spawning runs of alewife, blueback herring, and sea-trout still persist in the ARW, although at much below their pre-causeway abundances. Although it is evident that eels still occupy the system and there are some limited data to suggest that striped bass (probably non-spawning) have visited Pesaquid Lake in recent years, the findings do not provide a clear indication of the changes in the relative abundances of these species compared to pre-causeway conditions.

Chapter 5: Historical Overview of Potential Human-Induced Stressors

Changes in ecological conditions are usually the result of the long-term effects of numerous human-induced threats and natural factors, acting individually and in concert (cumulative and synergistic effects) (Kelso *et al*., 1996; Steedman *et al*., 1996; Pesch and Garber, 2001). For example, in an examination of all the known extinctions of freshwater fish in North America over the past 100 years, Miller (1989) determined that 82% were caused by the impacts of multiple human-induced factors. This chapter provides an historical overview and preliminary examination of the major human activities in the ARW over the past 300 years and their potential impacts on, and contributions to the changes in, the diadromous fish community. Since the upper ARW does not appear to have been accessible to diadromous fish (except for eels), the discussion focuses on threats to the lower ARW and estuary. Three general categories of threats are addressed: habitat degradation and loss, fishing pressure, and introduction of exotic fish species. In addition, there is a brief examination of the potential influences of natural/ecological factors and marine threats to the observed changes in ARW populations.

5.1 Habitat Degradation and Loss

Habitat degradation and loss (including access restrictions and obstructions to habitat) resulting from dams and other barriers, land-use changes, and water pollution are generally considered the most significant threats to diadromous and freshwater fish (Miller *et al*., 1989; Richter *et al*., 1997; Reynolds *et al*., 2002). The particular life history characteristics and habitat requirements of diadromous species, especially those classified as ‘intolerant’ or of ‘intermediate’ tolerance (which includes all BoF species except eels) and those that exhibit fairly high homing fidelities, make them particularly sensitive to habitat loss and degradation and impediments to access to natal spawning grounds and other critical habitats (see Section 2.3 and 2.4). For example, in a study on cold-water streams in the River Philip Watershed, Nova Scotia, Kanno (2002) found that as water temperatures increased and overall habitat quality decreased (speculated to have been the combined result of natural factors and human-induced habitat disturbance [e.g. agriculture, forestry, and urbanization]), intolerant and of intermediate tolerance cold- and cool-water species (specifically brook trout, brown trout [exotic], sea lamprey, Atlantic salmon, threespine stickleback, white sucker [freshwater], and dace spp. [freshwater]) were replaced by higher tolerance, warmer-water species (see also Kanno and Beazley, 2004; Kanno and MacMillan, 2004).

For the last 300 years, the habitat in the ARW, especially the lower portion, has experienced on-going disturbance and alteration as a result of human activities, which cumulatively appear to have been the largest contributing factor to local population declines and possible extirpations. The primary anthropogenic sources of habitat degradation and loss in the lower ARW have been dyking, agriculture, forestry, mills and mill-dams, hydro power development and associated water diversion, and the Windsor Causeway.

5.1.1 Types of Threats to Habitat

5.1.1.1 Water Quality Degradation

Pollution and poor water quality, especially in freshwater habitats, caused by human land-uses can have a significant effect on the productivity and persistence of diadromous populations (McDowell, 1988; Maitland, 1995; Richter *et al*., 1997; WWF, 2001). The following is a brief description of several water quality variables that are important to fish populations. Chemical contaminants, including pesticides from agriculture and forestry, and discharges from industrial facilities, can be toxic to fish species, directly affecting reproductive success or the survival and health of adults, eggs, and juveniles (Maitland, 1995; WWF, 2001). Pollutants at sub-lethal concentrations can increase a fish's susceptibility to other stresses (Maitland, 1995).

Eutrophication (over-enrichment of nutrients [nitrogen and phosphorous]) occurs when excessive concentrations of nutrient-rich contaminants, such as fertilizers, manure, sewage and paper mill waste, are discharged into streams and estuaries (McDowell, 1988; Pesch and Garber, 2001). This process depletes dissolved-oxygen concentrations through the promotion of oxygen-consuming bacteria (Evans *et al*., 1996). Moreover, the decomposition of high algal growth, which form in response to the higher nutrient concentrations (increase in primary productivity), further depletes dissolved oxygen concentrations. Low dissolved-oxygen levels can reduce the ability of fish to reproduce, capture prey, and grow and even can cause mortality, especially of juveniles and YOY.

However, it must be noted that at low nutrient-input concentrations, the increase in primary productivity could possibly benefit fish production (Downing *et al*., 1990).

Acidification of waterbodies can cause mortality, metabolic changes, reduced growth, and impaired reproductive success in many fish species (Moyle and Leidy, 1992) and has led to the extirpation of numerous diadromous fish populations (Watt *et al*., 1983; McDowell, 1988). Salmonids are especially vulnerable to acidification (Peterson and Gale, 1991). Peterson and Gale (1991) found that pH 5.0 and 4.7 were the lower limiting mid-summer levels for salmon and brook trout (and thus sea-trout), respectively, in several Nova Scotia systems. The rivers in south-western Nova Scotia have been severely affected by acidification since the 1970s due to the poor buffering capacity provided by the predominant underlying geology (granite bedrock) of the area (Watt *et al*., 1983; Davis and Browne, 1996). By 1980, this had resulted in the decline and extirpation of numerous salmon populations (Watt *et al*., 1983). In contrast, iBoF rivers are generally less susceptible to acidification due to the higher buffering capacity of the underlying carboniferous sediments (Amiro, 2003). iBoF rivers generally continue to exhibit good pH (>6) and thus acidification appears not to have been a major contributor to the declines of iBoF fish populations.

The siltation and sedimentation of freshwater streams threaten diadromous fish populations in a number of ways. Siltation and sedimentation can directly cause mortality in certain species (e.g. salmonids) by clogging gills (WWF, 2001) or smothering/suffocating eggs (Hynes, 1970; Grant *et al*., 1986). Sedimentation also affects substrate composition (e.g. burying of gravel), channel structure (e.g. filling in of pools), and other physical characteristics of streams and rivers resulting in the loss of natural habitat conditions and diversity, which are necessary for supporting the variety of habitat needs (spawning, rearing, feeding, and/or over-wintering) of the various species (Waters, 1995). Moreover, Waters (1995) observed that aquatic vegetation and benthic invertebrate populations were seriously harmed by excess sedimentation, thus reducing food availability and protective cover for young fish.

With the exception of white perch, all diadromous species in the BoF have been classified as cold- or cool-water species (refer to Table 2 in Section 2.4) and thus are particularly susceptible to human-induced habitat disturbances (e.g. the removal of riparian cover, alterations of water depth and flow, increased turbidity due to siltation, and global warming), which can cause elevated water temperatures (Kanno, 2002; Kanno and MacMillan, 2004). Elevated water temperatures can affect the survival, feeding behaviour, and reproductive ability of cold- and cool-water species (Hynes, 1970; Evans *et al*., 1996). Moreover, colder water can hold higher dissolved oxygen concentrations than warm water. Thus, increases in water temperature may lead to oxygen depletion in streams and pools, which at low enough levels may be harmful or lethal to spawning fish.

Since European settlement, human activities have affected water quality in the ARW through mill waste, agricultural and forestry run-off (e.g. pesticides, fertilizers, manure, and siltation), residential pollution (sewage, wastewater, and poor septic systems), gypsum mining, and other adjacent land-uses. Moreover, reductions in water quality in the estuary may have also impacted diadromous species. In addition to contaminants and sediments from the ARW and tributary river systems, historic and on-going sources of pollution to the estuary include agricultural run-off, discharges from commercial and industrial factories (the principal being pulp and paper plants and a textile factory), and untreated sewage and wastewater.

5.1.1.2 Deforestation and Riparian Cover Changes

Deforestation and the removal of riparian vegetation cover, as a result of agriculture, forestry, development, and other land-use practices, have been associated with the destruction or degradation of critical spawning and rearing areas in many BoF streams (Percy and Wells, 1997). Riparian buffer zones, among other functions, provide shade for streams (maintaining cool water temperatures), maintain stream and riverbank stability, and help filter and/or remove nutrients, chemicals and sediments from run-off from adjacent land-uses (Hynes, 1970; McDowall, 1988; WWF, 2001). Consequently, the removal of riparian vegetation can result in reductions in water quality (e.g. increased pollution and siltation), streambank erosion, higher water temperatures, and other negative impacts on fish habitat (Hynes, 1970; Grant *et al*., 1986; McDowell, 1988; WWF, 2001). The volume and pattern of water run-off into watercourses may be altered by a reduction in forest vegetation, thus affecting the hydrological conditions of fish habitat (Hynes, 1970; Maitland, 1995). Moreover, an increase in upland soil erosion due to vegetation loss may lead to siltation and sedimentation problems. The clearing of forest and riparian cover and the building of roads increase the accessibility of streams and therefore facilitate the introduction of non-native species and more intensive fishing pressure (J. LeBlanc, 2004, pers.comm.).

To date, there have yet to be any studies in the ARW comparing changes in forest and riparian cover with that of water/habitat quality or faunal populations. However, it is probable that this type of human-induced landscape alteration has affected the aquatic ecosystem of the ARW, at least in localized areas, and therefore played a role in the changes in the ARW diadromous fish community.

5.1.1.3 Human-Made Barriers

Dams, causeways, aboiteau, and other human-made in-stream barriers are built for a variety of purposes including flood control, water provision, power generation, and transportation (Wells, 1999). These structures "are often considered to be among the most destructive of human enterprises due to their overall negative impacts on aquatic ecosystems and hydrological resources" (Wells, 1999, p. 21). Richter *et al*. (1997) found that they were among the most significant threats to fish and other aquatic organisms in North America. Twenty-five of the 44 medium to large-sized rivers that flow into the BoF contain at least one significant human-made barrier (Wells, 1999). Research has only been conducted on a few of these rivers (not including the Avon River) and therefore the full nature and extent of the ecological effects of these structures is currently not well understood. Nevertheless, the construction of barriers, mostly without adequate provision for fish passage, has been the primary or major factor involved in the historic and contemporary local decline and extirpation of diadromous populations in numerous BoF and Maritime rivers (Knight, 1867; Vieth, 1868; Ambrose, 1890; Prince, 1903; Dunfield, 1985; Percy and Wells, 1997; Wells, 1999). For example, the causeway across the Petitcodiac River, New Brunswick, even with a fish-way (which has been largely ineffective for most species), has resulted in the significant decline and disappearance of the river's migratory fish species including salmon, gaspereau, shad, sea lamprey, tomcod, sea-trout, eels, and smelt (Niles, 2001). Currently, an environmental impact assessment (EIA) is in progress, whose objective is to evaluate options for permitting unimpeded fish passage through the Petitcodiac River Causeway with the goal of restoring fish populations (New Brunswick Department of Supply and Services [NSDSS], 2004).

Dams and other barriers affect diadromous fish in numerous ways. For more comprehensive reviews of the ecological effects of barriers see Baxter and Glaude (1980), Wells (1999), and WWF (2001). The full or even partial obstacle to migration presented by many barriers is one of the most potentially devastating threats to diadromous populations (Prince, 1903; Richter *et al*., 1997; Wells, 1999; WWF, 2001). Diadromous populations may be significantly reduced or even eliminated from rivers severely obstructed by barriers without adequate fish passage facilities by restricting, preventing, or delaying access to spawning and other critical freshwater habitat and/or migration back to sea (Prince, 1903; Maitland, 1995; Percy and Wells, 1997; Richter *et al*., 1997; Wells, 1999; WWF, 2001). Species that exhibit strong homing fidelity may be especially susceptible to population extinctions due to impediments to access to natal spawning grounds (see Section 2.3 and 2.4). Even when limited fish passage to and from freshwater habitat is permitted, smaller population sizes and increased stress can render populations more susceptible to genetic, demographic, and environmental factors or human-induced disturbances and therefore make them more vulnerable to extirpation.

Barriers can also degrade or destroy habitat, affect water quality, and alter the hydrological regimes of systems (e.g. fluctuations in water levels and streamflow, and restrictions of tidal movements) (Baxter and Glaude, 1980; Maitland, 1995; Richter *et al*., 1997; Wells, 1999; WWF, 2001). The regulation of water flow rates and patterns, especially related to hydro power generation, can have severe consequences for downstream freshwater ecosystems and therefore can be detrimental to the survival and productivity of diadromous fish populations. Fluctuations in flow rates and patterns can affect the survival of eggs and young and the reproductive ability of adults (Baxter and Glaude, 1980; Willson and Halupka, 1995) and reduce habitat quality and diversity (such as pools and riffles, and substrates), which are crucial for the various freshwater life stages of several diadromous species (Maitland, 1995; WWF, 2001). High flows can wash eggs downstream resulting in high mortality levels (WWF, 2001). Streambed erosion and siltation and the corresponding loss of critical habitat characteristics are often a consequence of periodic releases of large volumes of water. Bank erosion may also occur with sudden high flows, especially in areas where riparian vegetation has been thinned or removed due to forestry or other land-uses. This would result in further habitat degradation and increased siltation. In systems with severe water restrictions, migration may be impeded and fish stranded, spawning and rearing grounds dried out, and eggs exposed to the air (thus causing mortality) (Willson and Halupka, 1995; WWF, 2001). Elevated water temperatures and oxygen depletion occur when low water flows and levels are maintained for extended periods such as in dry summer months (WWF, 2001). These conditions can be lethal for fish, especially cold-water species (in the case of temperature). In addition to the on-going impacts from dam operations, the initial construction of barriers causes high levels of siltation and localized habitat degradation and destruction (Mills, 1991).

There have been four main types of human-made barriers that have existed in the ARW since European settlement: 1) dykes and small aboiteau on streams (1685-present); 2) mill-dams (18th to early 20th centuries); 3) hydro-power dams (1920s-); and 4) Windsor Causeway (1970-). Although few studies have been conducted to determine the individual or combined ecological effects of these structures, it is highly probable that this type of human activity has been one of the most significant stressors on the diadromous fish community in the ARW.

5.1.2 History of Habitat Loss and Degradation in the Avon River Watershed

5.1.2.1 Dykes

Extensive habitat alteration and degradation began immediately upon European settlement in 1685. Upon their arrival in the Pisiquid/Avon area, the Acadians constructed dykes along much of the tidal portion of the lower Avon River and estuary to convert the fertile salt marshes into productive agricultural lands (Nova Scotia Department of Agriculture and Marketing [NSDAM], 1987; Wells, 1999). This resulted in the disappearance of much of the salt marsh in the lower ARW, which had provided important nursery and/or feeding grounds for many diadromous species including tomcod, shad, striped bass, and smelt (Sangster, 1994; Daborn *et al.*, 2004). In the 1750s, the amount of dykeland (reclaimed salt marsh) in the Pisiquid (Avon) and Cobequid totalled 1000 hectares (NSDAM, 1987). The dykes were later expanded by English inhabitants (NSDAM, 1987) and maintained until the 1960s, at which time there was approximately 1,376 hectares of dykeland in the Avon area (Carroll, 2002). Dyking of salt marshes also involves the construction of aboiteau, sluice structures with hinged gates, in the bottom of the streams and creeks along the dykelands to prevent saltwater intrusion upstream while allowing freshwater to drain out (NSDAM, 1987). Although the early historic number of streams with aboiteau in the ARW is unknown, there were 36 by the 1960s (Carroll, 2002). These structures would have fully or partially impeded fish from accessing natal spawning areas. However, since there is no information on fish prior to or immediately following the construction of these structures, the extent of their impact on fish populations is uncertain. The aboiteau structures above the causeway were no longer required after its completion in 1970 and therefore, in the 1980s, most were removed (Carroll, 2002), potentially allowing access to areas of suitable habitat for freshwater species or diadromous species that could obtain passage through the causeway.

5.1.2.2 Agriculture, Forestry and Residential Development

Although the Acadians would have cleared some areas of land and riparian vegetation for agriculture and the establishment of villages (e.g. at sites of current towns of Windsor, Falmouth, Avondale, Hantsport), the upland forested area removed would have been relatively minor due to the small size of the population and the almost exclusive use of the productive dykeland (Acadians rarely cleared or used upland forests) (NSDAM, 1987). After the Acadian expulsion in 1755, the new English inhabitants, in addition to continuing to use and expand the dykelands, also began clearing uplands for agriculture (NSDAM, 1987). In addition to physical habitat alterations, early agriculture and loss of forest and riparian cover would have resulted in changes in water quality through increased inputs of nutrients and sediment. It is probable that these early land-use changes would have had some affect on fish populations and the aquatic ecosystem, although the nature and extent of the impacts are unknown.

Since European settlement, agriculture has been the predominant land-use (Dawson, 1857; MMRA, 1965; NSDAM, 1987) and thus a major non-point source of pollution in the lower ARW (A. Crowell, 2004, pers.comm.; KI#7, 20, 21). Sediment and manure run-off would have always been factors; however, the invention of modern intensive farming techniques (i.e. pesticides, chemical fertilizers, and larger densities of livestock) in the mid-20th century would have increased contaminant loading. According to some local sources (including farmers), agricultural run-off into the lower ARW and estuary continues to be a problem; however, there has been a marked improvement in nutrient and pesticide management practices and the overall environmental awareness and conscientiousness of farmers in the area over the past several decades (A. Crowell, 2004, pers.comm.; KI#7, 20, 21).

From the 1830s to the 1890s, ship-building and lumbering were major industries in the Avon area (Shand, 1979; NSDAM, 1987), which would have involved fairly substantial levels of forest harvesting. Forest fires in the early 1900s resulted in the loss of large areas of forest (KI#7, 10) and possibly the addition of large amounts of silt to streams. According to local KIs, the forest and riparian cover has greatly diminished throughout much of the watershed since the mid-1900s, primarily as a result of forestry activities (KI#1, 3, 7, 9, 10, 11, 19, 20, 25). The most significant changes in forest cover have occurred since the 1970s/80s, when extensive clear-cutting practices began in the watershed (KI#1, 3, 7, 9, 10, 11, 19, 20, 25). In many areas, cutting has occurred right up to the edge of stream and riverbanks, especially along the West Branch and its tributary streams (KI#7, 10, 11, 19, 20, 24). Local KIs associated the upland and riparian clearing with some observed degradation of fish habitat (specifically siltation problems, faster run-off into watercourses, fluctuations in water levels, and warmer water temperatures) (KI#7, 9, 10, 11, 12, 19, 20, 24, 25). Moreover, it appears that the clearing and associated road-building facilitated access to, and thus led to increased fishing pressure in, previously remote and intact areas of the West and Southwest branches (KI#1, 12, 19, 24, 26). Furthermore, since the 1950s forestry practices in Nova Scotia have involved the aerial spraying of pesticides (Wells, 1999; KI#17), which has been found in studies conducted elsewhere to be detrimental to fish populations and other aquatic organisms (caused mortality and affected reproductive ability) (WWF, 2001). Although clear-cutting is on-going in the ARW (KI#1, 3, 7, 9, 10, 11, 19, 20, 25), since 2002 stricter Provincial regulations have been established for the forestry industry, limiting harvesting close to watercourses (e.g. by imposing a minimum natural buffer zone requirement of 20 metres along watercourses that are 50 centimetres or more wide) (*Wildlife Habitat and Watercourses Protection Regulations***;** A. Crowell, 2004, pers.comm.).

Residential development has also increased substantially along the watercourses in the lower (and the lakes in the upper) ARW in the past few decades (A. Crowell, 2004, pers.comm.). In many areas, this development, as well as agricultural activities, has also involved the permanent/continuous removal of riparian vegetation and the degradation of riverbanks (A. Crowell, 2004, pers.comm.; KI#11, 20). In contrast to the forestry industry, there are currently no laws (i.e. municipal by-laws) restricting vegetation removal along watercourses or imposing minimum buffer zone requirements for agricultural or residential purposes (L. Davis, 2004, pers.comm.).

5.1.2.3 Point Sources of Water Pollution

Industrialization in the early 20th century has resulted in the on-going discharge of potentially harmful contaminants (chemicals, metals, organic materials, nutrients, suspended sediments) into the estuary from industrial facilities, the most significant being pulp and power plants in Hantsport (Minas Basin Pulp and Power and Keyes Fibre) and a textile factory in Windsor (Anon, 1934a; Anon, 1934b; Sutherland, 1935; Sangster, 1994; KI#8, 25). For example, in the 1930s (a few years after its establishment), the inhabitants of the Avon area complained that “the fish in the Avon river are being exterminated from the river owing to...the [pulp and paper plant in Hantsport] allowing sawdust and shavings, refuse and other deleterious matter to be carried into the river [estuary]” (Anon, 1934a). Historically, standards and controls related to the composition and concentration of effluents released from these industrial sources were fairly minimal. The negative effects of effluents on aquatic life and ecosystems have probably declined, to some extent, in the past several decades due to stricter government standards and more effective techniques, chemicals, and treatment systems.

To date, untreated sewage and wastewater from Windsor and Falmouth have been discharged into the tidal portion of the river (CBCL, 1994). Sewage effluent (containing excess nutrients) has been associated with oxygen depletion, eutrophic conditions, and decreases in macrofaunal (invertebrate food sources) diversity (McLusky, 1989; Pesch and Garber, 2001), which may be detrimental to diadromous fish migrating through or feeding in the Avon estuary. Discharges would have increased as the populations of the towns expanded, especially in late 19th and 20th centuries. Until ~1971, the outflow from the Windsor sewage system was located adjacent to the Town of Windsor (currently the Pesaquid Lake area) (Anon, 1971; CBCL, 1994). To avoid polluting Pesaquid Lake after the causeway was constructed, an interceptor line was installed to divert the effluent into the estuary. A portion of Windsor's effluent is lagoon treated and discharged into Tregothic Creek at the mouth of the St. Croix River, while the rest is discharged untreated directly into the mud-flat below the causeway (CBCL, 1994). An outlet still exists in Pesaquid Lake, which has occasionally overflowed and polluted the lake (CBCL, 1994).

From 1905 to the late 1920s, a salmon hatchery operated on Fall Brook, a tributary of LeBreau Creek (Prince, 1906; Rodd, 1930), which may have also been a source of localized nutrient contamination. By the mid to late 1920s, the hatchery's water supply (Fall Brook) was being contaminated by drainage from nearby gypsum quarries (Found, 1927; Bruce, 1928; Rodd, 1929, 1930; Anon, 1929). This contamination resulted in the mortality of the majority of eggs and fry and quickly forced the hatchery to close. The wild stocks in the streams were probably experiencing similar detrimental effects from this pollution (Found, 1927; Anon, 1929). Although available records did not provide an indication of how long the streams in the area continued to be polluted by the mining operations, KI#3 recalled that fish were fairly plentiful in the streams of the area in the late 1940s. Since it was established in the early 1970s (Nova Scotia Golf Association History Committee, 2004), a golf course adjacent to Allen Brook (a tributary of Pesaquid Lake) has been another major localized source of nutrients (fertilizer) to this watercourse and possibly Pesaquid Lake (see Section 5.1.2.6).

5.1.2.4 Mill-Dams

According to period documents, mill-dams and other artificial obstructions, through providing direct obstructions to fish passage and pollution inputs and possibly through alterations to hydrological and thus habitat conditions, were a principle cause of the 19th century collapse of diadromous fishes in the Maritimes (Knight, 1867; Vieth, 1868; Ambrose, 1890; Prince, 1903; Prince, 1910). Numerous saw-mill dams (as well as grist mills) were located on the South, West and Southwest branches from the 18th to the mid-20th century, only a few of which had adequate, or any, fish passage provisions (Court of General Sessions of the Peace for Hants County, 1812-1849; DMF, 1879; Rogers, 1887; Vieth, 1884; Butler, 1894; Hockin, 1894, 1914; Fisher, 1923; Loomer, 1996; KI#3). The obstruction of passage to and from spawning grounds and other critical habitats by dams in the ARW appears to have been a significant threat to diadromous species and, beginning in the 1820s, of great concern to fishery managers and local inhabitants (Court of General Sessions of the Peace for Hants County, 1812-1849; DMF, 1879; Rogers, 1887; Vieth, 1884; Butler, 1894; Hockin, 1894; Fisher, 1923). For example, in 1894, a local inhabitant described that:

> at present the passage of salmon and sea-trout up these rivers is almost totally obstructed. On the south branch an old mill dam (now entirely disused) exists at the head of tidal water; in this dam a ladder was inserted some years ago but I fear it has never been operative. Upon the west branch there are one or two small mills, the dams at which are so far as I know entirely without provision for passage of fish....Before the erection of the mill at the head of tide, the south branch was one of the finest salmon rivers in the province (Butler, 1894).

In addition to obstructing fish passage, many of the mills in the Avon River and tributary systems illegally discharged saw-dust and, to a lesser extent, other mill wastes into the rivers, which then apparently flowed into and accumulated in the estuary (Dominion Commissioner of Fisheries, 1898; McDougall, 1898; Prince, 1901, 1910; Found, 1912; Hockin, 1914; Blanchard, 1930). This pollution, especially the saw-dust, elicited considerable concern in the late 1800s and early 1900s among local inhabitants and fishery officers who believed it to be one of the primary reasons for the drastic decline in diadromous and marine fish from the Avon River and estuary. Saw-dust has similar effects on aquatic ecosystems and fish populations to siltation including clogging gills, smothering eggs, and killing aquatic vegetation and invertebrate food species (Prince, 1899). This substance was believed to have been especially detrimental to shad, gaspereau, and sturgeon (Knight, 1867; Rogers, 1879; Ambrose, 1890; Prince, 1899; 1910). Although changes in hydrological conditions and physical habitat were not specifically mentioned in historic accounts, mill-dams undoubtedly had such consequences.

5.1.2.5 Hydro Power Generation

In the early 1920s, the ARW began to be developed for hydro power generation (Shanks, 1994). The Avon River hydro power system is owned and operated by Nova Scotia Power Inc. and consists of a series of power dams, storage dams, and pipeline diversions (see Figure 2 in Section 1.2). Two power dams were installed on the lower South Branch, both without fish passage provisions, the first approximately 20 km upstream of Windsor and the second a further 90 meters upstream at the top of the South Branch waterfall. Storage dams were also built on the outlets of South Canoe, North Canoe, Zwicker, and Card Lakes in the upper ARW. In the mid-1930s, a dam was built on the outlet of Black River Lake, which formed the headwaters of the West Branch, diverting water flow into the Gaspereau River system (Smith, 1965).

Hydro power development has significantly impacted the watershed's aquatic ecosystem and therefore has probably been one of the primary reasons for the contemporary declines in fish populations. The diversion of the West Branch in the 1930s prevented fish migration into Black River Lake (Smith, 1965), which may have served as important historic spawning and rearing habitat for several ARW populations, most notably alewife, which prefer to spawn in lakes and pools. This potential loss of habitat may have lowered the production potential of the ARW for alewife and other species, thereby affecting overall population abundances. Although the two power dams on the South Branch, which do not contain fish passage provisions, have commonly been believed to have prevented anadromous fish from accessing historic natal spawning grounds in the upper South Branch and, in this way, have been a major contributing factor to population declines (Conrad and Semple, 1987; KI#5, 7, 9, 10, 11, 25), this does not appear to be the case. Historic documents indicate that even prior to the construction of these dams, the migration of anadromous fish into the upper ARW was completely obstructed by natural waterfalls on the South and Southwest branches (Government of Nova Scotia, 1816; Venning, 1869; Butler, 1894; Prince, 1910; Black, 1911; Found, 1911; Hockin, 1911; Bruce, 1918) and therefore the upper ARW did not provide historic habitat for anadromous species.

The major detrimental effects of the hydro power development on diadromous fish populations are likely to have been from the alteration of downstream hydrological conditions (e.g. water levels, flow rates and patterns), which subsequently affected water quality, disrupted habitat, and impeded fish migration. Unfortunately, studies assessing or monitoring the actual hydrological changes and resultant impacts on aquatic habitat conditions and organisms, if they exist (e.g. conducted by Nova Scotia Power), were not available. Nevertheless, anecdotal accounts from several sources suggest that hydro power operations on the South Branch and the diversion of Black River Lake from the West Branch have resulted in major alterations to the natural flow regimes on these branches, with fluctuations between periods of extreme low flow, where many stream and pool areas have completely dried up, to high flow conditions, when water has been released from the dams (Smith, 1965; Deemer and Skelhorn, 1983; Conrad and Semple, 1987; Jansen, 1987; KI#3, 4, 5, 9, 19, 25). These hydrological changes may have led to a decrease in the accessibility and quality of spawning and rearing habitat for salmon and other species. Water level fluctuations in the lower ARW have been exacerbated by the installation of the Windsor Causeway in 1970 (Conrad and Semple, 1987; Jansen, 1987).

Almost every year in the spring/summer, large numbers of fish die (especially gaspereau in recent years) in the area downstream of the power dam on the South Branch (G. Daborn, B. Sabean, A. Crowell, 2004, pers.comm.; KI#14, 28), which appears to be and/or have been an important spawning ground for salmon and gaspereau. Although the exact cause of these fish kills is uncertain, it is likely a consequence of dam operations. Possible contributing factors include elevated water temperatures resulting from the release of warm water from the headpond and/or low water levels, oxygen depletion, and fluctuations in water levels (when water is being stored in the headpond, the pool below often becomes completely dry) (G. Daborn, B. Sabean, A. Crowell, 2004, pers.comm.). However, the low pH values (<5.0) occasionally found in the area below the power houses may also play a role (see Section 5.1.2.7).

5.1.2.6 Windsor Causeway

In 1970, the Windsor Causeway was completed across the Avon estuary between the towns of Windsor and Falmouth. The causeway has arguably been the most prominent and controversial source of impacts on the ARW. The construction of this barrier has resulted in significant changes to the ARW and estuary ecosystems. Among many others, it has: 1) impeded fish passage to and from the ARW; 2) prevented saltwater from entering the ARW, thereby converting the watershed into an entirely freshwater system; 3) resulted in the formation of a reservoir (Pesaquid Lake); 4) altered the hydrological regime; and 5) caused the downstream accumulation of sediment, which has resulted in the formation of a mud-flat/salt marsh complex in the estuary extending (to date) as far as nine kilometres away (Daborn, 1997; Wells, 1999). Since few studies had been conducted on fish in the system prior to or after its construction, the extent of the tidal barrier's contributions to fish population declines is unknown. Nevertheless, the causeway, especially its restriction to fish migration, has likely been a major cause of diadromous fish declines in the last 35 years.

History

In the early 1960s, the MMRA proposed to build a causeway across the Avon River for the purposes of protecting 1,376 hectares of upstream farmland (dykeland) from saltwater and flooding and providing a highway linkage and replacing a rail bridge between the towns of Windsor and Falmouth (Kolstee, 2003). Although an EIA was not required or performed (since at that time, this was not yet a legal requirement), the provisions of the Federal *Fisheries Act* required that the existence and design of such a structure be assessed and approved by the DFO to ensure that it would not cause undue harm to commercial or sport fisheries resources.

In 1965, the DFO investigated the state of key anadromous species in the Avon River system to determine what effect a causeway might have on local fisheries (Smith, 1965). This study was apparently not published; however, the findings were presented in a letter from K.E.H. Smith, Biologist, to C.P. Ruggles, Chief Biologist (Smith, 1965). The report, for which no methods or sources of information could be ascertained, indicated that only small runs of salmon, smelt, sea-trout, gaspereau, and shad utilized the system, although they were more abundant in the past. The report concluded that

> the Avon River system presently has a very limited value to anadromous species. Its decline from earlier years is no doubt due mainly to extensive power development and diversion of water. Also, because of the power developments, there appears to be little chance of re-establishing most species to any significant levels. Thus, construction of a causeway in the Windsor area would add little to the loss already experienced (Smith, 1965, p.3).

Despite this conclusion, DFO biologists recommended that serious consideration be given to the installation of a fish-way to maintain the remaining runs of anadromous species (Smith, 1965).

Initially, a flap-gate fish-way structure was considered (Ruggles, 1969). However, it was rejected because it would have permitted some saltwater intrusion above the causeway and the Town of Windsor desired a freshwater reservoir. Alternative options for fish passage facilities were estimated to cost $100,000 (1968 dollars) (DFO, 1968; Lucas, 1968; Ruggles, 1969). In 1968, the Minister of Fisheries gave approval for the causeway to be constructed without fish passage facilities (Lucas, 1968). The rationale for the decision was that "the expense [was] not warranted for the few migratory fish in the system" (Lucas, 1968), especially since resident brook trout, the only important fishery (recreational) in the system, would possibly be benefited by the increase in freshwater habitat (DFO, 1968; Lucas, 1968).

It should be noted that, as per the directives under the *Fisheries Act,* the DFO's decision to allow the construction of a causeway across the Avon River without fish passage facilities appears to have been primarily based on its assessment of the consequences of such a structure to the maintenance of or future potential for economic benefits from the fisheries resources in the river (Smith, 1965; Ruggles, 1969). Ecological, conservation, genetic, intrinsic, or other values of the ARW fish populations appear to have not been major considerations in the decision-making process.

Moreover, the depressed state of fish populations reported in the DFO documents is generally inconsistent with the observations of KIs and other local residents. Although locals generally agreed that anadromous species had declined by the 1960s, they asserted that relatively fair-sized runs persisted on the river until the construction of the causeway. Therefore, the accuracy and reliability of the description of the state of anadromous species upon which the DFO decisions were based is uncertain, especially since the methods and sources of information are unknown (e.g. was it based on local knowledge? [i.e. did they talk to local residents or fishery officers?] or did they conduct sampling efforts?). Furthermore, it seems curious that in 1968 (when the decision was made), DFO documents (DFO, 1968; Lucas, 1968) were stating that no salmon had been reported in recent years, even though the 1965 study reported the existence of small runs (Smith, 1965). The discrepancy between DFO documents and local sources could be a reflection of stakeholder biases and interests regarding the causeway, which may have, consciously or unknowingly, caused perceptions and interpretations of the status of fish to have been skewed (Steedman *et al*., 1996). For example, the various interests (e.g. Provincial government and Town of Windsor) in favour of constructing a causeway and in a cost-effective manner may have influenced the DFO's interpretation of the 1965 study results and led to an overestimated perception of the insignificance of anadromous runs and thus threats to potential fisheries posed by a causeway. Conversely, the negative opinions of some local stakeholders towards the past and future impacts of the causeway may have led them to recollect larger fish abundances and smaller declines prior to, and therefore more significant declines following, its construction. Moreover, recreational fishers may have been unaware of the extent of declines due to advances in fishing gear technology (Post *et al*., 2002), lower water levels (e.g. from hydro power operations) or other factors, which may have enhanced the detection and capture of fish even as populations declined.

Fish Passage Considerations

A significant deterioration in ARW fish populations has been experienced since the causeway's construction in 1970, to which the causeway may have been a principle contributing factor. Diadromous fish have specific migration characteristics and requirements, which vary between species and sometimes populations, including time of year, time of day (light levels), and water quality preferences (e.g. salinity, temperature and water flows) (McDowall, 1988; NBDSS, 2004). Since the causeway was neither designed nor has been directly operated to accommodate these needs, the ability of fish to migrate between the ARW and estuary has been limited. Due to the absence of any fish passage facilities, the only opportunities for upstream and downstream migration are when the gates are opened, which has not always occurred during the times or under the conditions required for each species (Table 10). Moreover, freshwater discharges from tidal rivers (attraction flow) provide cues for anadromous fish to begin upstream migrations (McDowall, 1988; NBDSS, 2004). Thus, the disruption of natural flow characteristics (e.g. timing, salinity, temperature and rate) by the causeway may sometimes prevent upstream migration or cause delays that could affect spawning ability.

Table 10: Timing of Gate Openings Required to Accommodate Fish Passage Needs of Key Diadromous Species

Season	Upstream Migrations	Downstream Migrations
Spring (April to June)	▪ gaspereau (spawning) ▪ spring-run salmon (spawning) ▪ smelt (spawning) ▪ shad (spawning) ▪ eel	▪ sea-trout ▪ tomcod (juveniles) ▪ striped bass (after over-wintering) ▪ salmon (juveniles) ▪ smelt (juveniles and spent adults)* ▪ gaspereau (spent adults)
Summer (July to August)	▪ gaspereau (end of spawning) ▪ sea-trout (spawning)	▪ eel (spawning) ▪ gaspereau (juveniles and spent adults) ▪ salmon (juveniles and spent adults) ▪ shad (juveniles)
Fall (September to November)	▪ fall-run salmon (spawning) ▪ striped bass (over-wintering)	▪ shad (juveniles) ▪ eel (spawning) ▪ salmon (spent adults)
Winter (November to February)	▪ tomcod (spawning)	▪ tomcod (spent adults)

Sources: Leim (1924); Peterson *et al*. (1980); Williams and Daborn (1984); Stewart and Auster (1987); Loesch (1987); Scott and Scott (1988); Stokesbury and Dadswell (1989); Fortin *et al*. (1990); Jessop (1999, 2000); NSDAF (2001a, 2001b); Amiro (2003); DFO (2003); Douglas *et al*. (2003); Gibson and Myers (2003); Daborn *et al*. (2004)

The NSDAF has the primary responsibility for managing the causeway gates (to protect upstream farmland), in coordination with the DFO (to manage fish and fish habitat) (K. Carroll, pers.comm., 2004). During normal operations, the gates are controlled with the goal of maintaining Pesaquid Lake at a specific level, usually ~2.74 m (9 ft) (Kolstee, 2003). The gates are only opened on out-going tides when the lake rises above the pre-determined level and is within 15.2 cm (6 in) of the tide level (Carroll, 2002). The gates are then closed when the tide level is rising and is equal to the lake level. The duration of a gate opening is usually approximately eight hours, but may be less in drier conditions. The gates are not opened on every out-going tide, the frequency depending on the amount of water in Pesaquid Lake (K. Carroll, 2004, pers.comm.). The less often the gates are open, the less opportunity for fish to get to and from spawning and feeding grounds. The gates can be opened as much as twice a day, which usually occurs during periods of high runoff (e.g. early spring runoff or when excess water is released from the hydro dams), to perhaps only a few times a month, as is the case during dry summer and early fall conditions (Conrad and Semple, 1987; Kolstee, 2003; K. Carroll, 2004, pers.comm.). Therefore, fish passage opportunities may be quite limited, especially for summer and fall upstream (e.g. fall-run salmon, sea-trout) and downstream (e.g. gaspereau, salmon) migrating species. Moreover, in the late fall and winter, when tomcod undertake spawning migrations, the lake levels are kept high (~3.04 m or 10 ft) (Kolstee, 2003) and therefore the frequency of gate openings during this time would be low. Since sources could not provide local or scientific knowledge on fish in the winter months, it is uncertain whether these conditions have been adequate for tomcod, assuming the species historically spawned in the ARW.

The fish passage conditions were improved in 1988, when the size of the gate opening was changed from 1.22 m (4 ft) from the bottom to 0.61 m (2 ft), which meant that water would drain from the lake more slowly allowing for more frequent openings (K. Carroll, 2004, pers.comm.). It is uncertain whether or to what extent this change in operating procedure aided fish populations as downward trends in abundance continued in all runs, and the last report of salmon occurred in 1986.

In most years between 1980 and 1999, for two to three weeks in May the gates have been kept open and the lake level lowered during the low tide period (as long as the lake level was higher than the tide) during working (daylight) hours in order to conduct maintenance on the gates. However, in some years the drawdown period would only be a week or less and sometimes would not occur at all (K. Carroll, 2004, pers.comm.). The May drawdown generally corresponds with the peak spawning migrations of several important anadromous species (spring-run salmon, gaspereau, shad, smelt, striped bass) and appears to have provided more favourable conditions for the passage of these fish compared to when the lake is maintained at normal levels (i.e. ~2.74 m or 9 ft). According to the majority of sources, gaspereau, smelt, striped bass, and salmon have mostly been observed in years when the drawdown occurred (see Chapter 4). In years without the extended drawdown (either not at all or for only a short time), fewer, if any, anadromous fish were noticed. Prior to 1980, gate maintenance occurred in September (followed similar procedure to the May period) (K. Carroll, 2004, pers.comm.). Although few species undertake spawning migrations in September, the downstream migrations of adult eels and juveniles and spent adults of several anadromous species may have been facilitated by the extended gate opening during this time (refer to Table 10 and Section 2.3). The reason for the change to the spring was that the lake would be too dry in the fall after a dry summer to be able to maintain the gate opening for a long enough period to undertake maintenance (K. Carroll, 2004, pers.comm.).

In 1999, the gates were improved so that they required only a few days of maintenance a year and thus the extended drawdown period was no longer necessary (Hubley, 2003). In 2003, to facilitate fish passage (mainly concerned with gaspereau) during the spring migration period, the DFO requested that the lake be lowered for a consecutive three week period (low tide during daylight hours) in May. Possibly as a result, some locals reported that gaspereau were more plentiful in 2003 than they had been in many years (Daborn *et al*., 2004; KI#5, 29).

In addition to specific times of the year, many species prefer to migrate at particular times of the day, depending on light levels (McDowall, 1988; NBDSS, 2004). Therefore, regardless of the frequency or duration of openings during migration seasons, a species' opportunity for fish passage may have also been limited if the gates were not opened at the appropriate time of day. For example, the May (and September) extended gate opening periods have been limited to daylight hours, potentially reducing their value for eels, which prefer to migrate at night (Jessop, 2000).

It must be noted that even when the gates are open at the appropriate times, conditions may not always be suitable for fish passage. One major limiting factor concerns the high-velocity water flow through the barrier (Daborn *et al*., 2004; Haro, 2004; Haverstock, 2004). In order for fish to enter the ARW they must swim against the out-going current. Therefore, fish would only be able to migrate upstream through the causeway when their maximum swimming speed is higher than the velocity of the water as it flows through the gates (Haro, 2004; Haverstock, 2004). The current velocity is related to the difference between the lake level and tide level (head difference), the larger the difference the higher the velocity (Haverstock, 2004). The head difference and thus velocity is smallest at the beginning of the gate opening. During both the current normal operating conditions (i.e. lake level maintained at 2.74 m or 9 ft and gate open to 0.61 m or 2 ft from bottom) and the May drawdown period conditions, there appears to be only a limited interval for fish to migrate upstream since the velocity at the gates becomes too high for fish to overcome only a few minutes after opening (Daborn *et al*., 2004; Haverstock, 2004).

Haverstock (2004) estimated that during the normal operating conditions, the smaller species (alewife and smelt) had, on every gate opening, two intervals of less than five minutes to pass through the gates, which occurred when the head difference was small (~0.70 ft) just after initial opening and just before closure, assuming the gates remained open for the entire tide cycle. Eels had less than three minutes (head difference <0.40 ft.). Smaller individuals of the larger species (shad, salmon, sea-trout, and striped bass) had two periods approximately 53 minutes in duration, and average-sized Atlantic salmon had two approximately 80 minute intervals during each opening. Although estimations were not performed for blueback herring and tomcod, due to their small size, they would likely have similar intervals to alewife and smelt. However, since the May drawdown period would produce a much smaller head difference, this operation may provide more favourable conditions for fish passage (Hubley, 2003; Daborn et al., 2004), as evidenced by the larger numbers of fish (mainly gaspereau) seen in years when this has occurred.

The partition between entirely freshwater and saltwater imposed by the causeway is another important factor that could affect the survival of some migratory fish. Fish that have been able to migrate through the gates (up and downstream) would experience an abrupt change in salinity and temperature between salt and fresh water. The ability to tolerate changes in these conditions associated with the transition between fresh and seawater varies between species and between different life-stages within species (McDowall, 1988). Many anadromous species require a gradual transition in order to physiologically acclimatize to different salinity and temperature conditions (McInerney, 1964; Leggett, and O’Boyle, 1976; McDowall, 1988). Leggett and O’Boyle (1976) found that a rapid shift from salt to freshwater and its related temperature changes put considerable physiological stress on shad, which resulted in high mortality. A similar phenomenon has been seen in juvenile salmonids when transitioning from fresh to saltwater (McInerney, 1964; McDowall, 1988) and has affected the survival of Atlantic salmon attempting to pass through the Petitcodiac River Causeway, New Brunswick (Harvey, 1997). Moreover, the ability of certain species (e.g. salmonids) to acclimatize to differences in salinities is often limited to specific times of the year, thus premature or delayed migration may affect survival (McDowall, 1988).

Effects on habitat

In addition to fish passage constraints, the causeway has also significantly altered upstream habitat conditions. The causeway converted the ARW into an entirely freshwater system, thus resulting in the loss of approximately 32 km of brackish/estuarine habitat and any remaining salt marsh (not already reclaimed by dykes) (Harvey *et al*., 1998). Therefore, a considerable area of important nursery and feeding habitat for several species was eliminated, although a small increase in salt marsh has since formed below the causeway. Moreover, considerable bank erosion initially occurred as a result of the die off of salt-tolerant streambank vegetation (K. Carroll, 2004, pers.comm.). As freshwater species eventually became established, most of the banks began to re-stabilize. In the 1980s, the NSDAF installed bank stabilization structures in areas along the lower river where erosion continued to be a problem. Extreme water flow restrictions and fluctuations would have also resulted in the accumulation of sediments and pollutants in the ARW, especially Pesaquid Lake, which would affect habitat quality (Wells, 1999). Moreover, the barrier would have interfered with nutrient transfer to and from the ARW and Minas Basin, thus potentially affecting the productivity of both systems.

Nonetheless, as well as the obvious benefits to freshwater species, the causeway may have also had some beneficial consequences for diadromous species (assuming they have been able to get into the system through the causeway) by increasing the amount of potential freshwater spawning and rearing habitat. Most notably, the formation of Pesaquid Lake has provided a substantial area of potential spawning and rearing habitat for alewives and thus has likely increased the production potential of the ARW for this species (Conrad and Semple, 1987; J. Gibson, 2004, pers.comm.; R. Bradford, 2005, pers.comm.). The creation of large headponds behind dams has been found to enhance the production of this species in several other rivers in the BoF (Jessop and Parker, 1988; Jessop, 1990). However, large water level fluctuations in Pesaquid Lake caused by flow releases from the South Branch power dams can be harmful to alewives and therefore have been of concern in the ARW (Conrad and Semple, 1987; Hubley, 1987). This problem was ameliorated in the late 1980s by improved communication and coordination between the power dam and Windsor Causeway operations. Furthermore, as previously mentioned, the removal of the 36 dyke aboiteau from streams in the lower ARW may have provided additional spawning habitat for some species.

5.1.2.7 Recent Water Quality Assessments

Water quality has been poorly monitored in most BoF watersheds (Wells, 1999), including the ARW, where only recent data are available. The key results of water quality surveys of the lower ARW conducted in 2003 on water temperature, dissolved oxygen, and pH (Daborn *et al*., 2004) and nutrient concentrations (NSDAF, 2004a) are presented below. Since historic data are unavailable, it cannot be determined if, how, and to what extent water chemistry conditions have changed over time (deteriorated or improved).

In 2003, nitrogen and total inorganic phosphorus concentrations occasionally exceeded levels which could cause eutrophication (0.30 mg/L and 0.01 mg/L, respectively) at sampling sites on LeBreau Creek and Sangster's Bridge (NSDAF, 2004a) (Table 11). However, neither Daborn *et al*. (2004) nor NSDAF (2004a) indicated evidence of eutrophic conditions at those sites, and Daborn *et al*. (2004) found that the lower ARW was relatively well-oxygenated. The highest nutrient concentrations of the locations sampled, which frequently exceeded the levels which could cause eutrophication, were found in Allen Brook, a tributary of Pesaquid Lake (NSDAF, 2004a). Daborn *et al*. (2004) observed large amounts of algae in this brook, which suggests a nutrient enrichment problem. In addition to contributions from agriculture, which is the prevalent land-use at all the sites, the higher concentration of nutrients in Allen Brook is likely explained by fertilizer run-off from a golf course in the area (Daborn *et al*., 2004; NSDAF, 2004a). NSDAF (2004a) found that nutrient concentrations were often high in Pesaquid Lake. Nevertheless, Daborn *et al*. (2004) found that Pesaquid Lake showed little evidence of eutrophic conditions and generally maintained good dissolved oxygen levels, despite the potential for problems due to nutrient loading from surrounding land-uses and outflow from Allen Brook. However, occasionally in the middle of the summer, the deeper waters of Pesaquid Lake were undersaturated in dissolved oxygen, but rarely at levels (below 50% saturation) considered detrimental to fish and other aquatic organisms. Daborn *et al*. (2004) suggested that the low oxygen concentrations may have been due to a lack of vertical mixing associated with low water flow conditions occurring during the dry summer months.

Table 11: Maximum and Mean Nitrogen and Inorganic Phosphorus Concentrations at Several Locations in the Lower Avon River Watershed Taken in 2003

Location	Max. Nitrate-N (mg/L)	Mean Nitrate-N (mg/L)	Max. Inorganic P (mg/L)	Mean Inorganic P (mg/L)
Allen Brook	0.64	0.35	0.19	0.07
Sangster's Bridge	0.33	0.21	0.06	0.05
Pesaquid Lake	0.66	0.31	0.16	0.07
LeBreau Creek	0.43	0.23	0.13	0.05

Source: NSDAF (2004a)

The primarily carboniferous underlying geology of the ARW should provide good buffering capacity against the effects of acid precipitation. Daborn *et al*. (2004) found that pH was generally good (~ or >6.00) in most of the sites sampled in the lower ARW (Pesaquid Lake, the West Branch, LeBreau Creek, and Allen Brook) (Table 12). However, pH occasionally fell below 5.0 on the South Branch below the power dams (range 4.56 to 6.60), which may partially explain the large annual fish kills in that location (see Section 5.1.2.5). A pH of <5.00 can be harmful to acid-intolerant species such as salmonids (Peterson and Gale, 1991; WWF, 2001).

Table 12: Mean and Minimum pH Values Taken at Several Locations in the Lower Avon River Watershed in 2003

Location	Minimum pH	Mean pH
Pesaquid Lake	5.10	6.13
Allen Brook	5.90	6.61
Sangster's Bridge	4.88	5.75
West Branch	5.17	5.90
South Branch below power house	4.56	5.35
LeBreau Creek	6.05	6.56

Source: Daborn *et al*. (2004)

Maximum and mean summer water temperature data suggest that most of the lower ARW currently exhibits characteristics of a cool-water system (19-25°C, according to classification system used by Coker et al., 2001) (Table 13). These temperatures may provide slightly unfavourable conditions for cold-water species, which make up the majority of diadromous species that may occupy the ARW. Unfortunately, since previous data are unavailable, it is uncertain whether the current temperatures are similar to historic conditions or represent a warming of the water due to decreased riparian cover or alterations of streamflow patterns. However, KIs have suggested that temperatures in several locations throughout the lower ARW have warmed since extensive clear-cutting began in the 1970s/80s (KI#7, 10, 11, 12, 24). Moreover, the historic abundance of cold-water species in the system, such as salmon, smelt, and gaspereau, suggests that water temperatures may have been lower in the past.

Table 13: Maximum and Mean Summer Water Temperatures at Several Locations in the Avon River Watershed Taken in 2003

Location	Max. Temperature (ºC)	Mean Temperature (ºC)
Pesaquid Lake	25.6	23.7
Allen Brook	21.7	20.3
Sangster’s Bridge	24.7	22.4
West Branch	24.6	23.4
South Branch below power house	24.4	23.5
LeBreau Creek	23.7	21.6

Source: Daborn *et al*. (2004)

5.2 Fishing Pressure

Fishing pressure (including over-fishing and biological and ecological consequences of catching and/or removing fish), coupled with habitat deterioration and loss, is commonly identified as one of the primary causes of declines and extirpations of riverine fish stocks, both target and non-target (Maitland, 1995; Smith and Clugston, 1997; Policansky, 2002; Reynolds *et al*., 2002). The spatial and temporal concentration of diadromous species in rivers (e.g. the entire population must pass through the lower section of the river at specific and known times) makes them particularly easy to harvest and thus especially susceptible to over-harvesting (McDowall, 1988; Maitland, 1995; Metcalfe *et al*, 2002). For example, nets or weirs placed at the mouths of rivers can result in the removal of entire populations. In addition to affecting the abundance of sport fish species, inappropriate fishing and fishery management practices can alter food webs (by adding or removing species) and the composition of biological communities and can affect the feeding, spawning and social behaviour of fish (Policansky, 2002). For example, fishing pressure on a target species can indirectly affect other fish and aquatic organisms through changes in competitive and trophic (predator-prey) interactions (Kaiser and Jennings, 2002). Late maturing species such as Atlantic sturgeon and eel are easily vulnerable to population extinctions or declines through over-harvesting since: 1) a large proportion of individuals can be removed before getting a chance to spawn; and 2) these species have a low intrinsic rate of increase and therefore populations are slow to increase in numbers (Smith and Clugston, 1997; Waldman and Wirgin, 1998). In fact, Smith and Clugston (1997) identified over-harvesting as the single major cause of declines in Atlantic sturgeon in North America. Although thought to be one of the major historic threats to diadromous species in the BoF (Dunfield, 1985), fishing pressure is generally considered to have played a lesser role in modern (late 20th century) declines and extirpations of most species (Percy and Wells, 1997; Wells, 1999).

Fishing pressure on diadromous species in the ARW and estuary has undoubtedly had some effect on fish populations. However, due to the absence of systematic, long-term commercial or recreational catch statistics for the Avon River, the actual extent of and trends in fishing pressure are unknown. The following description of fishing pressure in the river system has been obtained primarily from fishers' knowledge (either from historical documents or KIs). It must be noted that fishers often have biased perceptions towards the impacts of their activities on fish resources and thus may underestimate the role of exploitation in the changes in fish populations (Mackinson and Nottestad, 1998). Nevertheless, fishers' observations on fishing activities and the state of the resources are often accurate (Neis *et al*., 1999).

In the past 300 years, the majority of fishing activity in the ARW and Avon estuary has been undertaken for recreational purposes. Recreational fishing includes both fishing for sport/fun and for home consumption (Cowx, 2002). There have also been some small-scale seasonal commercial (drift-nets, weirs) fishing activities conducted in the estuary. Historically, it appears that much of the recreational fishing effort in the ARW was focused on diadromous species, especially salmon and, to a lesser extent, smelt and gaspereau. However, by the 1960s, resident trout had become the most important fishery in the ARW (Smith, 1965). Nevertheless, diadromous fishes were and continue to be popular (MacEachern, 1968; Deemer and Skelhorn, 1983; KI#1, 3, 9, 10, 11, 13, 19, 20, 21, 24, 25, 26, 28). In the estuary, shad, salmon, and gaspereau have been the primary commercially targeted diadromous fish (Perley, 1852; KI#14, 16) and striped bass and tomcod have been popular recreational species (KI#4, 7, 8, 9, 11, 13, 14, 16, 25, 26). The commercial fishery in the estuary declined in the mid-1900s, probably as a result of declining interest and fish abundances (KI#14, 16).

As the human population increased throughout the 18th century, fishing pressure would have intensified. Nevertheless, since the population at the time was still small and subsisted mostly on farming, the impact on stocks was likely relatively minimal (Dunfield, 1985). By the late 1700s, salmon were being commercially harvested and exported from the estuary (Hollingsworth, 1787), as well as potentially other species such as gaspereau, shad, and eels (Clark, 1968; Dunfield, 1985).

By at least the early 1800s, concerns were being raised about the effects of fishing pressure and harvesting practices on migratory populations (fisheries), specifically salmon and gaspereau, on the South and West branches. These concerns would eventually lead to the establishment of fishery regulations in 1843 (*Hants County Fishery Regulations, 1843*). The earliest reference found to problems was in 1823 by the Court of General Sessions of the Peace (1812-1849), which recorded concerns about local inhabitants placing nets across the South Branch, whereby few or no fish could pass to spawning grounds. In 1868, the Fishery Officer for Nova Scotia suggested that such activities were one of the primary causes of the absence of fish in the river (Venning, 1869). Several local fishery overseer reports from the 1800s and early 1900s indicated that fishing-related problems, including poaching and the use of harmful and/or illegal harvesting methods, were common in the ARW (Venning, 1869; Hockin, 1896, 1897; Salter, 1915; Arnold, 1930). In the estuary, over-harvesting and fish passage impediments caused by weirs and drift-netting were affecting the numbers of fish returning to the ARW to spawn (*Hants' County Fishery Regulations, 1843, 1852-3;* Perley, 1852; Hockin, 1902; Prince, 1910).

In the 20th and early 21st centuries, recreation has been the main reason for fishing, and resident brook trout and salmon (at least until the 1970s/80s) have been the primary sport/subsistence fishes. KIs and other local sources suggested that over-fishing and illegal fishing activities have been a problem in the ARW since, at least, the mid-1900s, especially for salmon, smelt, and brook trout (which would include sea-trout) (MacEachern, 1968; Deemer and Skelhorn, 1983; KI#1, 9, 10, 11, 13, 19, 20, 24, 26). As remote fishing areas became more accessible as a result of land-clearing for development, forestry, and road-building, the numbers of anglers in the watershed increased (KI#11, 13, 19, 20, 24, 26). This coupled with technological advances in fishing gear likely intensified the angling pressure on recreational species. This phenomenon began in the 1950s and 1960s (KI#13, 20), but was especially noticeable from the 1970s to 1990s, when extensive areas of land were being logged and developed and thus made more accessible (KI#11, 19, 24, 26). KIs also suggested that many fishers have not respected fishery regulations such as bag and size limits, and that government monitoring and enforcement has generally been negligible (KI#9, 10, 11, 24, 26). Deemer and Skelhorn (1983) identified salmon poaching on the South Branch as a serious problem in the early-1980s.

5.3 Fish Introductions

Until recently, enhancement of fisheries by stocking of native and non-native species has been the dominant management approach used by most fishery management agencies in Europe and North America to deal with depleting native sport fish populations (Lichatowich *et al*., 1999; Policansky, 2002). However, recently it has been recognized that stocking can have serious detrimental effects on native biodiversity and ecosystems, often causing or exacerbating declines in native fish populations (Berrill, 1997; Lichatowich *et al*., 1999; Cowx, 2002; Post *et al*., 2002).

The introduction of non-native species, such as smallmouth bass (*Micropterus dolomieu*), brown trout (*Salmo trutta*), and chain pickerel (*Esox niger*), often results in the declines or extirpations of native fish stocks or other organisms through increased predation and/or competition for food and space (Berrill, 1997; Richter *et al*., 1998). Moreover, the non-native species may hybridize with a native stock/species, which results in the loss of genetic diversity and the native stock/species. The recognition of the risk to native biota of introducing non-native species has made this practice less popular with fishery management agencies in recent years (Berrill, 1997). However, legal and illegal introductions continue to be a major problem.

In addition to non-native species, the stocking of native hatchery-reared fish has been an extremely popular management practice throughout Europe and North America since the late 19th century, used to maintain commercial catch rates and recreational fishing opportunities despite serious population declines in the native wild stock (Lichatowich *et al*., 1999; Cowx, 2002; Post *et al*., 2002). Even though the detrimental effects of this practice on native wild stocks (causing or exacerbating declines) and the ecosystem are now recognized, it continues to be a prevalent management measure for native species recreational fisheries throughout North America. First, stocking permits the maintenance or intensification of fishing pressure directed on depleted wild stocks (Post *et al*., 2002). Second, hatchery-reared fish can introduce diseases and parasites to wild populations and the ecosystem (Lichatowich *et al*., 1999). Third, after thousands of years of natural selection, wild fish stocks have become well-adapted to their local ecosystems. Therefore, interbreeding with hatchery-reared fish (which have traits adapted to hatchery environments and/or the river from which their parent stock originated [which is usually not the system being stocked]) can lead to the loss of the wild stock's well-adapted traits, as well as genetic diversity, which makes the population (and the species) more vulnerable to natural environmental perturbations (Lichatowich *et al*., 1999). Fourth, stocking efforts intended to maintain catch levels can mask the severity of declines in wild stocks (Post *et al*., 2002), thereby delaying needed conservation measures. Finally, the reliance on stocking as a management technique can divert funding and effort away from more appropriate and effective conservation-oriented measures such as habitat rehabilitation and protection, fishing effort restrictions (e.g. bag limits or fishery closures), and public education (Lichatowich *et al*., 1999; Redmond *et al*., 1999).

In 1877, to maintain and augment the fishery in light of a major stock depletion, the Federal DMF began releasing hatchery-reared Atlantic salmon (primarily from parents originating from the Miramachi River, New Brunswick) in the ARW (DMF, 1880). Although the DMF attributed much of the recovery of the species in the late 1800s to this management practice (Wilmot, 1887; Rodd, 1915), and it may have contributed to the experienced improvement in catch success, it does not account for the simultaneous recovery of other diadromous species. From 1905 to the late 1920s, a hatchery operated on Fall Brook (tributary of LeBreau Creek), which supplied salmon for distribution throughout the ARW and Nova Scotia (Prince, 1906; Bruce, 1928). Salmon eggs for the local hatchery were generally supplied from non-local (Miramachi River, NB) parent stock. Salmon stocking continued until the 1930s when efforts shifted toward brook trout. Brook trout stocking is still a prevalent practice undertaken by fishery management agencies (e.g. NSDAF) and angler groups to enhance recreational fisheries in the lakes and streams of the upper and lower ARW (J. Leblanc, 2004, pers.comm.; KI#10).

The introduction of non-native species does not appear to have been a major factor in the depletion of diadromous stocks. However, smallmouth bass appear to have displaced resident (non-anadromous) brook trout as the dominant species in several lakes in the upper ARW, where they have been illegally introduced since ~1996 (NSDAF, 2004b; KI#3, 7, 9, 10, 11, 25). Smallmouth bass introductions often result in declines in native lake fish due to predation and competition (J. Leblanc, 2004, pers.comm.).

Only two KIs observed smallmouth bass in the lower ARW (except Meadow Pond) in the last 15-20 years (KI#4, 12). They appear to be fairly localized to the stillwaters in a small area on the West Branch near the diversion dam and do not seem to have spread or become established anywhere else in the lower ARW. This is likely because bass in Nova Scotia prefer to occupy pond habitats rather than running water (J. Leblanc, 2004; pers.comm.). These fish may have been illegally introduced or have spilled over from the Black River system (where they have been legally stocked since the 1960s) when water was released from the dam. There is no indication that they have had any effect on diadromous species in the lower ARW. Smallmouth bass, rainbow trout (*Oncorhynchus mykiss*), and chain pickerel have also been legally stocked in Meadow Pond (an offline pond in the lower ARW) since the 1950s, but escapement into adjacent streams has been, for the most part, prevented (J. Leblanc, 2004, pers.comm.).

Two KIs reported what they thought to be brown trout in the lower ARW. KI#7 had observed them in the early 1900s, but had not seen any in recent years. KI#9 said he had heard of a few being caught in the last few years. Moreover, an unofficial survey of fishery officers completed around 1970 suggested the presence of brown trout in the system (Anon, 1973). However, brown trout is difficult to identify and is often confused with salmon; thus, it is possible that these sources had been mistaken (M. Brylinsky, 2004, pers.comm.; B. Sabean, 2004, pers.comm.). Moreover, there are no official records of brown trout stocking in the ARW and no other sources mentioned the species in the system. If brown trout were present in the system, it is unlikely they represented a spawning population. It is more probable that they were occasional wanderers from the nearby Cornwallis or Stewiacke Rivers, where a population became established after stocking efforts in the late 1800s and early 1900s (M. Brylinksky, 2004, pers.comm.; J. Leblanc, 2004, pers.comm.; R. Bradford, 2005, pers.comm.). In other North American rivers, brown trout are known to compete with both Atlantic salmon and brook trout and often displace native salmonids, especially brook trout, where they are introduced (Waters, 1983; Hearn, 1987). However, since it is likely that brown trout, if ever present, were only occasional visitors to the ARW, their effect on diadromous stocks was probably negligible.

5.4 Natural/Ecological Influences

Natural population fluctuations, weather events, and ecological changes may have also influenced the changes in ARW diadromous populations. In addition to short-term fluctuations in population abundances resulting from annual or seasonal variations in environmental conditions (e.g. unusually dry or wet conditions, unseasonable temperatures), natural ecosystems and biotic communities are dynamic and ever evolving. Therefore, it would be expected that, even without human interference, some long-term changes would have occurred over time. Moreover, biodiversity is connected through complex webs of ecological interactions (e.g. predation, competition, and mutualism) (Mills *et al*., 1992; Willson and Halupka, 1995; Kaiser and Jennings, 2002; Persson, 2002) and processes (e.g. nutrient cycling) (Durbin *et al*, 1979; Bilby *et al*, 1996; Stockner and MacIsaac, 1996). Thus, the impact of a human activity on one species (fish or non-fish) could have ripple effects, resulting in the alteration of the structure of the entire biotic community and the loss of ecosystem integrity (Kaiser and Jennings, 2002). For example, the decline or removal of a top predator (e.g. Atlantic salmon) may allow an increase in abundance of some prey species, with a subsequent intensification of predation on a lower trophic species and so on (Pace *et al*., 1999; Kaiser and Jennings, 2002). Alternatively, the loss or decline of a fish prey species from an ecosystem may subsequently affect the survival of the terrestrial and aquatic predators and scavengers dependant on it (Willson and Halupka, 1995; Pace *et al*., 1999; Kaiser and Jennings, 2002). Such processes are known as 'trophic cascades' (Pace *et al*., 1999).

5.5 Marine Anthropogenic Threats

According to the literature, the most significant threats to diadromous species are human-induced activities in riverine habitats (Miller *et al*., 1989; Richter *et al*., 1997; Reynolds *et al*., 2002; McDowall, 1988; WWF, 2001). Nevertheless, it must be noted that diadromous species are also exposed to stresses, including pollution, fishing pressure, and habitat destruction, in the marine environment. Above normal mortality of diadromous fish at sea may result in fewer fish entering tidal river watersheds, which would thus have ecological consequences for the entire watershed ecosystem and its biological community. Recent studies conducted on several other iBoF salmon populations indicated that marine survival was a major limiting factor for population growth and replacement (Amiro and Jefferson, 1996; Amiro, 2003). For example, Amiro and Jefferson (1996) determined that the marine survival of Stewiacke River, Nova Scotia salmon ranged from 0.00 to 0.42%. This level of survival was significantly lower than the estimated 3.57% required for replacement of the population (Amiro, 2003). Furthermore, scientific opinion is that this unexplained high rate of marine mortality has been a significant factor in the recent (since 1990) drastic decline and endangered status of the whole iBoF Atlantic salmon sub-species (Amiro, 2003; DFO, 2004). Although the reasons for the low marine survival are uncertain, ecological changes in the BoF and the impacts of aquaculture (pollution, spread of disease, and escapees mixing with wild populations resulting in loss of wild genetic traits) have been suggested. Therefore, marine threats may have played an especially important role in the recent declines and possible extirpation of Atlantic salmon.

5.6 Summary

Since European settlement, the individual and cumulative effects of human activities in the ARW (and in some cases natural variables and marine threats) have likely been significantly impacting the watershed's diadromous fish community. Although the exact nature and extent of the impacts of early settlement activities on diadromous fish populations cannot be determined from the limited information available, habitat degradation and loss due to dyking and other development activities and increased exploitation pressure may have had some detrimental effects on population abundances and viability. By the mid to late 1800s, human-induced stresses, especially obstructions to migration by dams, saw-dust and other mill pollution, and over-fishing, had resulted in a major depression in the abundances of anadromous fish (specifically salmon, smelt, sea-trout, gaspereau, and shad). Fishery managers at the time attributed the higher returns of salmon to stocking efforts. Although these activities may have played a role in the reported increase in abundance of salmon, this explanation does not account for the concurrent improvement of the other species. However, the study was unable to pinpoint other potential reasons for the recovery.

The frequency and magnitude of human-induced stresses on aquatic ecosystems and biodiversity in the watershed have increased substantially since the early 20th century. Since that time, anadromous populations have experienced major declines, the most substantial having occurred since 1970. It is probable that hydro power operations and especially the Windsor Causeway have played prominent roles in these changes. However, other human-induced stresses in the watershed, including industrial pollution, increased human population pressures (e.g. residential and commercial development, sewage discharges, and exploitation) and modern intensive agriculture and forestry practices have likely also been important contributing factors.

Chapter 6: Recommendations and Conclusions

6.1 Recommendations

6.1.1 Conservation and Recovery Planning

To redress the drastic declines of diadromous fish populations in the ARW, the elimination, mitigation, and prevention of the human-induced causes of fish declines and habitat degradation and destruction must be addressed (Bradshaw, 1996; Steedman *et al*., 1996). A comprehensive watershed management strategy which employs a long-term ecosystem-based approach, including monitoring and adaptation, would support and promote the recovery/conservation of all native diadromous populations, contribute to overall aquatic (and probably terrestrial) biodiversity and ecosystem conservation, and help prevent the development of future threats and problems (Sheldon, 1988; Willson and Halupka, 1995; Bradshaw, 1996; Kelso *et al*., 1996; Steedman *et al*., 1996). Habitat restoration, species re-introductions, and other efforts that are targeted at particular species or symptoms may also be worthwhile or necessary for successful fish conservation/recovery (Bradshaw, 1996). However, due to the limited scope of the benefits that accrue from initiatives targeting specific areas or species, such tasks should be combined with a broader ecosystem-based approach, as complementary components of a conservation strategy (Steedman *et al*., 1996).

The results of this study have shown that, while there are many synergistic and cumulative stressors in the ARW and estuary, a high priority for the conservation/ recovery of diadromous fishes is to address the fish passage and tidal flow restrictions caused by the Windsor Causeway. Without this, the benefits derived from efforts directed at other stresses will be minimal. This is especially pressing due to the Nova Scotia Department of Transportation and Public Works’ intention to expand or modify the causeway to provide extra traffic lanes as part of the twinning of Highway 101. To facilitate the implementation of courses of action that are compatible with the conservation and recovery of diadromous fishes, an assessment of the ecological, social, and economic implications of potential options for restoring/improving fish passage and habitat conditions should be conducted and incorporated into the development of, and EIA and decision-making processes on, expansion/modification project alternatives.

In addition to the knowledge on the ARW and its diadromous fish community obtained from the current study, the assessment/decision-making processes may benefit from insights gained in the EIA process currently being conducted on options for restoring unimpeded fish passage through the Petitcodiac River Causeway, New Brunswick, BoF. Despite containing a fish-way (which has been largely ineffective), since this causeway's completion in 1968, major declines or extirpations have been experienced in most of the river's historic diadromous populations (salmon, gaspereau, shad, sea lamprey, tomcod, sea-trout, eel, and smelt) as a result of tidal flow and fish passage restriction (Niles, 2001; NBDSS, 2004).

To provide the best opportunity and conditions for the successful recovery and long-term conservation of all known or potential historic runs (and possibly over-wintering striped bass), the objective should be to find and implement courses of action that will restore unimpeded fish passage through the system during the peak up and downstream migration periods of each species (see Section 2.3 and Table 10 in Section 5.1.2.6). This would entail the modification of either the causeway's structure or gate management to provide conditions compatible with the particular migration characteristics and requirements of each species, particularly ensuring no impediments to migration and sufficient attraction flows during the appropriate times of year and day.

Potential options to evaluate for accomplishing fish passage objectives include: 1) installing a fish-way; 2) gates kept open during peak up and downstream migration periods of all species; 3) gates kept open permanently; and 4) replacing part of the causeway with a bridge. The Petitcodiac EIA study found that neither option 1 (being the replacement of the existing fish-way) nor 2 would be capable of meeting the objective of restoring adequate fish passage for all species (NBDSS, 2004). Nevertheless, these options should be evaluated based on the unique conditions in the Avon River. However, similar to what was determined for the Petitcodiac River (NBDSS, 2004), it is unlikely that a fish-way facility (option 1) of any design will be able to effectively accommodate the up and downstream migration needs of all species in the tidal and sediment conditions in the Avon River. Moreover, since the gates would need to be open from April of one year to February of the next year, during the day and evening/night (e.g. for gaspereau, shad, and smelt) (see Section 2.3 and Table 10 in Section 5.1.2.6), option 2 (gates kept open during peak periods) would essentially need to become option 3 (gates kept open permanently, except for March) to accommodate the up and downstream fish passage requirements of all species.

Options 3 and 4 (replacing causeway with bridge) would permit unimpeded fish passage and restore relatively natural tidal flow conditions to the river at all times throughout the year. Therefore, options 3 and 4 appear to be the most viable options for achieving fish passage objectives (which reflects the finding of the Petitcodiac study [NBDSS, 2004]). However, due to the reestablishment of tidal flow to the system, these options would have other consequences which would need to be considered including: 1) the loss of the freshwater Pesaquid Lake, which may reduce a substantial area of potential spawning and rearing habitat for alewives (see Sections 4.2.3 and 5.1.2.6), as well as affect recreational opportunities for the local community; 2) the possible erosion of the salt marsh/mudflat complex currently forming in the estuary; and 3) the need for the reinstallation of dykes to protect upstream farmland from saltwater flooding or, alternatively, the natural regeneration or restoration of upstream salt marsh wetlands and floodplains. Salt marsh regeneration/restoration would be the preferable alternative from an ecological perspective since these ecosystems, among other functions, are important habitats for diadromous fish, migratory birds, and other wildlife.

This study has shown that the hydro power system has had a major detrimental impact on fish populations in the ARW, although the exact extent could not be determined (see Section 5.1.1.3 and 5.1.2.5). Although the elimination of this stressor (i.e. by ceasing hydro power operations and removing the dams) should be considered as a possible course of action, it is not likely to be supported by the owners of the system (Nova Scotia Power Inc.) in the near future. Therefore, at minimum, it is recommended that: 1) an operational procedure is adopted for the South and West Branch dams that ensures adequate water levels and flow, and prevents or mitigates unnatural hydrological fluctuations on these branches at the times of the year when diadromous fishes would be expected to be present; and 2) the cause of the fish kill problem below the South Branch power dams is determined and addressed. These actions would require an assessment of the downstream ecological effects of the current and potential alternative operational procedures.

Moreover, consideration should be given to installing fish passage facilities into the West Branch diversion dam to allow ARW alewife and other species access into and out of a substantial area of potential historic spawning and rearing habitat in Black River Lake (which was part of the ARW prior to the dam's construction in the 1930s and has now been diverted into the Gaspereau River system) (see Sections 4.2.3 and 5.1.2.5). However, the fish passage facility should be designed to prohibit smallmouth bass, which are stocked in Black River Lake, from entering the ARW. Fish passage provisions do not appear to be necessary for the South Branch power dams since the upper South Branch was not historically accessible to anadromous species due to a natural waterfall, and it appears that eels are still able to access this area (see Section 4.1 and 5.1.2.5).

With the exception of the causeway and hydro power, most of the stressors on diadromous fish and fish habitat are the consequences of the cumulative actions of individual local land-owners, farmers, fishers, industries, and other users of the river system (e.g. through exploitation pressure, water pollution, and riparian and upland vegetation removal). It is recommended that these stressors be addressed through a combination of legal enforcement measures and community and commercial environmental education and stewardship programs. The latter could be undertaken through partnerships of government (Federal, Provincial and Municipal) agencies and local environmental organizations such as Hants West Wildlife Association, Friends of the Avon River, Wildlife Habitat Advocates, and Avon River Watershed Coalition. Although fishing may currently be only a minor stressor in the ARW, KIs have suggested that illegal- and over-fishing are problems. Consequently, increased monitoring of recreational fishing activities and enforcement of regulations are needed, which could include the use of local volunteer monitors.

Habitat conservation is a key aspect of ecosystem-based management (Bradshaw, 1996; Steedman *et al*., 1996). Through a combination of legal and voluntary stewardship initiatives, important areas of diadromous fish habitat (spawning, rearing, over-wintering) in the ARW should be protected and restored. These areas would need to be identified through further research efforts. Additionally, much of the riparian vegetation along the watercourses in the lower ARW have been thinned and removed for forestry, agriculture and residential/recreational use purposes (see Section 5.1.2.2). These areas are important components of fish habitat and they moderate in-stream temperature fluctuations (see Section 5.1.1.2); therefore, they should also be protected and restored. The new Provincial minimum buffer zone regulations for forestry (*Wildlife Habitat and Watercourses Protection Regulations*) should be enforced and similar laws and by-laws at the Provincial and Municipal levels be established for residential, agricultural, and commercial uses. Programs should be implemented that facilitate and encourage the replanting of riparian zones with appropriate native vegetation. Similarly, forestry companies should be encouraged or required to replace clear-cutting activities, which sources suggest are prevalent in the ARW, with more selective forest harvesting techniques (see Section 5.1.2.2 and 5.1.1.2). This could reduce the potential for siltation and sedimentation problems and reduce fluctuations of hydrological conditions in fish habitat (Hynes, 1970; Maitland, 1995).

Moreover, potential sources of water pollution should be addressed. According to several sources, nutrient (fertilizers) and pesticide run-off from agriculture, forestry, residential, and commercial/recreational (e.g. golf course on Allen Brook) activities are major sources of water quality degradation in the watercourses of the lower ARW and Avon estuary (see Section 5.1.2.2). To reduce the potential run-off of these contaminants and thereby ameliorate water quality/fish habitat conditions, it is recommended that efforts be undertaken to encourage and/or enforce the adoption of nutrient and pesticide best management practices. Similarly, there should be improvements in sewage and wastewater treatment and controls and regulations of industrial discharges (from the pulp and power and textile plants) into the estuary (see Section 5.1.2.3). This could reduce the potential for nutrient enrichment and bacterial, toxic chemical, and heavy metal contamination in the estuary, which may be harmful to diadromous fish migrating through or feeding in this area of the Avon River system.

An important consideration in any decision-making and environmental assessment process should be the recovery of the probably extirpated ARW salmon population. In addition to having beneficial ecological consequences for the Avon River system, this would contribute to the conservation and recovery process for the highly endangered iBoF Atlantic salmon. Even with the species' precise homing to natal rivers, the rate of straying can be sufficient to permit natural re-colonization of extirpated systems if favourable habitat conditions have been restored (Thorpe, 1994; McDowall, 1996). However, due to the extremely small numbers of iBoF salmon remaining in the wild (<200 adults), the re-establishment of an ARW population may require the artificial re-introduction (stocking) of the species, in addition to other management measures (Amiro, 2003; DFO, 2004). Regardless, the above-mentioned conservation measures, especially regarding fish passage, would improve the probability of the successful and sustainable restoration of the iBoF Atlantic salmon population.

6.1.2 Future Research

Further research and on-going monitoring are recommended to aid in the conservation/restoration planning and decision-making process, to identify new problems if and as they arise, and to ensure that reliable long-term information is available for future needs. Systematic surveys are required to ascertain accurate estimates of the current status (e.g. presence [of salmon, tomcod, sea lamprey, and striped bass], size and health) and characteristics (e.g. the particular timing of and environmental requirements for migrations and spawning) of diadromous populations in the ARW and to monitor long-term trends in abundance and health. Habitat assessments (physical, chemical, and biological) should be conducted to determine and monitor the current and future quantity, quality, and location of spawning, rearing, and other habitat in the ARW for each diadromous species. Habitat assessments can be used to estimate the carrying capacity or production potential of the system for each species (i.e. the population size that the system is capable of producing/supporting) and to identify critical habitat areas that need restoration or protection. Aerial photos, which have been taken each decade since the 1930s, could be used to determine past changes in broad-scale physical habitat conditions (e.g. size and depth of watercourses and lakes at a certain time of year, riparian vegetation, and adjacent land-uses) and to identify habitat degradation and loss over time.

Although this thesis provides an overview and general examination of the potential impacts of major historic and contemporary stressors in the ARW and Avon estuary, it is recommended that further analyses are undertaken on the potential past and on-going effects of these stressors on each individual diadromous species. Due to the lack of historic scientific data, patchy nature of the anecdotal information available, cumulative and synergistic effects, and other factors mentioned in Section 3.2, it is difficult to make any definitive conclusions regarding the causes of the past changes in ARW fish populations. However, additional valuable insights into the possible contributions of each stressor to the changes in each separate population may be provided by a more thorough speculative analysis based on the specific biological characteristics and requirements of each species and on the research and experiences in other river systems. Furthermore, a comprehensive scientific assessment should be undertaken to determine the individual and cumulative ecological effects of all current human-induced stressors (especially hydro power development and the Windsor Causeway) and potential mitigative measures (see Section 6.1.1).

In addition, although the extent of Mi'kmaq traditional ecological knowledge (TEK) on the fish in the ARW is uncertain, it may be a valuable source of additional historical information. Thus, the incorporation of local Mi'kmaq TEK with the information synthesized in the current study may be a useful research endeavour. Due to its holistic nature, the inclusion of TEK could help resolve some of the gaps and uncertainties encountered in the current study by providing a better understanding of the status of fish species (possibly those species for which little or no other knowledge exists) and the relationships and connections between the species, other ecosystem components, and human activities (Haggan *et al.*, 1998).

6.2 Conclusion

Until this thesis was undertaken, there was considerable uncertainty in regards to the historic and contemporary characteristics of ARW diadromous fish populations, the nature and degree of degradation over time, and the individual and cumulative impacts of human-induced stressors in the ARW, especially in regard to fish passage and tidal flow restrictions through the Windsor Causeway. This uncertainty has led to controversy and disagreement surrounding what, if any, actions should be taken to conserve/restore these species. The proposed expansion/modification of the causeway as part of the twinning of Highway 101 has further intensified concerns and questions regarding the impacts of this tidal barrier.

With the purpose of providing information for diadromous fish and overall watershed conservation planning and decision-making, this thesis endeavoured to improve knowledge on the historic status of, the nature and degree of changes in, and the potential impacts of human-induced stressors on ARW diadromous fish populations, from European settlement to the present. The study applied an interdisciplinary historical approach, which integrated both scientific and anecdotal sources of information including interviews with local knowledge holders and experts, written historical, archival and contemporary records, fisheries catch statistics, existing scientific fish surveys, and museum specimens.

The case of ARW diadromous fishes provides a clear illustration of the value of using an interdisciplinary approach, which includes non-scientific/local knowledge sources of information, to develop an understanding of past ecological systems and trends, where rigorous historic and long-term quantitative/scientific data are lacking. This thesis provides invaluable insight into the historic status of, trends in, and potential impacts of stressors on the ARW diadromous fish community, which could not have been gained through traditional scientific approaches.

The findings confirm that the ARW supported historic spawning populations of anadromous Atlantic salmon, alewife, blueback herring, rainbow smelt, and sea-trout, as well as populations of catadromous American eel. Historic populations of these species are known to have been fairly common throughout BoF rivers (see Section 2.3). Some evidence was also located to suggest that there may have been a historic spawning population of American shad in the ARW, which is significant since this species has been confirmed to have spawned in only a few rivers in the BoF (Chaput and Bradford, 2003). Although a few sources identified striped bass and tomcod in the ARW, these data did not indicate the presence of spawning. There is no evidence of sturgeon or sea lamprey having ever entered the ARW. Striped bass are known to enter the Shubenacadie River and several other Minas Basin rivers in the late fall to over-winter (Wirgin *et al*., 1995; Douglas *et al*., 2003). KI#7's account of a historic fall migration into the ARW could suggest such a past (and perhaps continued) use of the system.

Although information on current conditions is still limited, the findings suggest that salmon, which have not been reported in the ARW since the late 1980s, have probably been extirpated. Moreover, there has been no indication of shad in the ARW (whether representing a spawning run or migrants of non-local origin) since the completion of the causeway in 1970. Populations of alewife, blueback herring, smelt, and sea-trout still persist in the ARW, although at much below their historic abundances. Of these, the most pronounced changes have been observed in smelt, which has declined to an extremely low abundance. Eels still occupy the watershed; however, data are conflicting as to the species' relative abundance compared to past conditions.

Declines in anadromous species have been noted since the mid-19th century. A brief recovery period was experienced in the late 19th to early 20th centuries, followed by a significant declining trend throughout the mid- to late-20th century. The results are mixed regarding the extent of anadromous fish declines prior to the construction of the Windsor Causeway. Government documents from the 1960s reported that anadromous populations had declined to low abundances by the mid-1960s, most likely a result of hydro power operations; whereas local sources asserted that, although declines had occurred since hydro power development, fair-sized populations persisted until the 1970s. Nevertheless, according to the majority of sources, major changes in anadromous fish populations have occurred since 1970. These changes began to manifest immediately upon or within a few years of the causeway's completion.

The cumulative effects of over 300 years of human activities have contributed to the depletion and probable extirpation of anadromous species (and possibly eel) from the ARW. Due to the patchy and anecdotal nature of the information available, cumulative and synergistic effects, and other factors mentioned in Section 3.2, it was not possible to make any definitive correlations between the impacts of a particular stressor and specific changes experienced by fish populations. However, the findings confirm that hydro power operations on the South and West branches (1920s/30s-) and the Windsor Causeway (1970-) have been the most significant 20th century stressors on diadromous populations and fish habitat, with the causeway probably the primary cause of the major declines and extirpations experienced since its construction. Other major historic and contemporary stressors which have probably negatively impacted diadromous fish have been identified as: mill-dams (obstruction to fish passage) (19th-early 20th century); saw-dust and other mill pollution (19th-early 20th century); over-exploitation and illegal fishing practices; removal and thinning of riparian zones and nutrient and pesticide pollution due to forestry, agriculture, residential and commercial purposes; and sewage and industrial pollution into the Avon estuary (20th century).

Such experiences have not been isolated to the ARW. As a result of tidal barriers and other obstructions to fish passage, hydro power development, over-exploitation, and other human-caused habitat degradation and loss, diadromous species in many Nova Scotian and BoF rivers have experienced declining trends throughout the 19th and 20th centuries (Knight, 1867; Vieth, 1868; Ambrose, 1890; Prince, 1903; Prince, 1910; Dunfield, 1985; Jessop, 1993; Percy, 1997; Percy and Wells, 1997; Jessop, 1999; Wells, 1999; Chaput and Bradford, 2003; Douglas *et al*., 2003; Gibson *et al*., 2003). Consequently, numerous historic populations have become severely depleted or extirpated. The continued and increasing pervasiveness of these problems creates serious concerns for ecological integrity of the region's rivers and the persistence and recovery of species-at-risk of extinction, especially the iBoF Atlantic salmon, which has declined by 99.5% since the mid-20th century (Amiro, 2003; DFO, 2004).

There are still several gaps and uncertainties related to the presence/absence and changes in relative abundance of particular species, pre-1800s and pre-causeway conditions, and the relative impacts of particular stressors. Gaps and uncertainties (e.g. related to specific time periods or species) are an inherent limitation of historical studies which rely on incomplete archival and anecdotal sources of information (Steedman *et al*., 1996; White and Walker, 1997). The comprehensiveness of historical studies of this type is dependant on the nature, amount, and consistency of available records (records had to have been made at a particular time period and maintained over time) and the existence of local knowledge on the subject (Steedman *et al*., 1996). Few historic or contemporary written records have been either created or maintained on the diadromous fishes in the ARW. Current local knowledge is also limited, possibly a reflection of the low importance of fishing in the ARW in the 20th century, which may itself be a sign of depleted fish stocks. Historic records and local knowledge also tend to be primarily concerned with fish species of commercial and sport value in the local area at the particular time (Steedman *et al*., 1996), which may be a reason for the lack or limited amount of data on tomcod, sturgeon, sea lamprey, eel, striped bass, white perch, and stickleback spp. in the ARW. Moreover, tomcod, which spawn in freshwater in the winter, may have gone unnoticed since fishers tend to only be aware of fish present during fishing seasons (spring to fall) (Neis *et al*., 1999). Consequently, despite a lack of evidence, there still remains the possibility of historic spawning runs of tomcod, striped bass, sturgeon, and sea lamprey.

Anecdotal data can also be subject to inaccuracies created by personal biases and attitudes, interpretations based on limited understanding, and memory loss of the record maker or local knowledge holder (Steedman *et al*., 1996; Mackinson and Nottestad, 1998; Neis *et al*., 1999; Johannes, 2000). Since it is often not possible to directly gauge the reliability of sources, this can create a degree of uncertainty in the results (e.g. regarding relative abundances). Such problems may have played a role in the inconsistency between sources found in this study regarding the relative abundance of anadromous species prior to the construction of the Windsor Causeway.

Historic studies on the changes in and threats to diadromous fish populations in individual river systems, such as this thesis, are invaluable for informing fish and watershed conservation/restoration planning and decision-making. The information on the ARW gained from this research can be used: to define conservation/restoration goals and to identify and evaluate the success of measures to achieve those goals (Ryder and Kerr, 1989; Kelso *et al*., 1996; Steedman *et al*., 1996; White and Walker, 1997; Robertson *et al*., 2000; Pesch and Garber, 2001); to gain stakeholder support for mitigation, conservation, restoration, and/or stewardship efforts (Steedman *et al*., 1996; Pesch and Garber, 2001); and to inform decision-making so that future problems may be avoided (Kelso *et al*., 1997; Steedman *et al*., 1997; Robertson *et al*., 2000).

The results of this study indicate that, while numerous human activities in the ARW, estuary, and marine environments have contributed to declines in diadromous fishes in the ARW, the Windsor Causeway has clearly had a major detrimental effect. The mitigation or elimination of fish passage and tidal flow restrictions is a necessary action for the successful restoration and long-term conservation of native populations. It is, thus, crucial that this is a priority consideration in the development and decision-making process regarding the future expansion/modification of the causeway. However, the causeway has clearly not been the only factor involved in the depletion of fish populations. The pervasiveness of human-induced stressors in the ARW illustrates the need for an ecosystem-based watershed management strategy, which addresses all potential stressors and includes fish habitat conservation, preventative measures, and continued monitoring. Such a strategy will also benefit the overall ecological integrity of the Avon River system and may contribute to the persistence and recovery of species-at-risk such as the iBoF Atlantic salmon.

References

Ambrose, J. 1890. Art. IX - Our fishes and their enemies. Proceedings and Transactions of the Nova Scotian Institute of Natural Science, 7: 394-403.

Amiro, P.G. 2003. Population status of inner Bay of Fundy Atlantic salmon (*Salmo salar*), to 1999. Canadian Technical Report of Fisheries and Aquatic Sciences, 2488. 44p.

Amiro, P.G., J. Gibson, and K. Drinkwater. 2003. Identification and exploration of some methods for designation of critical habitat for survival and recovery of inner Bay of Fundy Atlantic salmon (*Salmo Salar*). DFO Canadian Science Advisory Secretariat Research Document 2003/120. 29p.

Amiro, P.G., and E.M. Jefferson. 1996. Status of Atlantic salmon in Fishing Area 22 and 23 for 1995, with emphasis on inner Bay of Fundy stocks. DFO Atlantic Fisheries Research Document 96/131. 16p.

Anderson, J.E. 1991. A conceptual framework for evaluating and quantifying naturalness. Conservation Biology, 5(3): 347-352.

Anon. 1929. Hants to Have Hatchery? Halifax Herald. 3 May 1929.

Anon. 1934a. "Petition signed by fishermen and others along the shores of the Avon River, Minas Channel and Minas Basin, and waters adjacent thereto". To the Honourable R.B. Bennett, Prime Minister of Canada and Monsieur Durenndeau, Minister of Fisheries. Dated 7 July 1934. National Archives of Canada, Ottawa, ON, RG23, acc. 71/324, vol. 434, file 702-2-4.

Anon. 1934b. Protest List Continues to Swell as Avon Fishermen Fight Sawdust. Halifax Chronicle. 9 July 1934.

Anon. 1971. Roadway Causing Concern. Chronicle Herald. 22 October 1971.

Anon. 1973. Sport fish occurrence as reported by fishery officers ~1973. Unpublished Document. Obtained from B. Sabean, Nova Scotia Department of Natural Resources, Kentville, NS.

Arnold, E.M. 1930. Report to D.H. Sutherland. Dated 22 July 1930. National Archives of Canada, Ottawa, ON, RG23, acc. 80-1/260, vol. 712, file 714-4-1 pt.12.

ASE Consultants Inc. 1995. Recreational fishery catch statistics from the creel census program, 1985 – 1993 for various freshwater and anadromous fish species of Nova Scotia. Prepared for Fisheries Institute of Nova Scotia and Nova Scotia Department of Fisheries. Halifax, NS: ASE Consultants Inc. 137p.

Avise, J.C., G.S. Helfman, N.C. Saunders, and L.S. Hales. 1986. Mitochondrial DNA differentiation in North Atlantic eels: population genetic consequences of an unusual life history pattern. Proceedings of the National Academy of Sciences of the United States of America, 83(12): 4350-4354.

Babbie, E.R. 1992. The practice of social research. Sixth Edition. Belmont, CA: Wardsworth Publishing Co.

Baxter, R.M., and P. Glaude. 1980. Environmental effects of dams and impoundments in Canada: experience and prospects. Canadian Bulletin of Fisheries and Aquatic Sciences, 205: 34p.

Beamish, F.W.H. 1980. Biology of the North American anadromous sea lamprey, *Petromyzon marinus*. Canadian Journal of Fisheries and Aquatic Sciences, 37(11): 1924-1943.

Berrill, M. 1997. The plundered seas: can the world's fish be saved? San Francisco, CA: Sierra Club Books. 208p.

Bilby, R.E, B.R. Fransen, and P.A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. Canadian Journal of Fisheries and Aquatic Sciences 53(1): 164-173.

Black, J.B. 1911. Letter from J.B. Black, House of Commons, to A. Johnston, Esq., Deputy Minister of Marine and Fisheries. Dated 4 February 1911. National Archives of Canada, Ottawa, ON, RG23, vol. 225, reel T-3143, file 1248.

Blanchard, N. 1930. Letter from N. Blanchard, Barrister to Minister of Fisheries. "Re: petition re saw mill-Avon River Hants Co., N.S". Dated 25 November 1930. National Archives of Canada, Ottawa, ON, RG23, vol.315, reel T-4000, file 2586.

Bradshaw, A.D. 1996. Underlying principles of restoration. Canadian Journal of Fisheries and Aquatic Sciences, 53(Suppl. 1): 3-9.

Bruce, C. 1918. Memorandum for the Superintendent of Fisheries. "Re: Falls in the Avon River, Hants Co.". Dated 6 September 1918. National Archives of Canada, Ottawa, ON, RG23, acc. 80-1/260, vol. 801, file 719-3-11 pt. 2.

Bruce, C. 1928. Appendix No. 4. Report of C. Bruce, Fisheries Engineer. In Sixty-First Annual Report of the Fisheries Branch, Department of Marine and Fisheries, for the Year 1927-28. p. 143-151. Ottawa, ON.

Buckley, J.L 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) – rainbow smelt. U.S. Fish and Wildlife Service Biological Report 82(11.106). 11 p.

Butler, W.R. 1894. Letter from W.R. Butler, Professor, Kings College, Windsor to Honourable C.H. Tupper, Minister of Marine and Fisheries. Dated 27 July 1894. National Archives of Canada, Ottawa, ON, RG23, vol.225, reel T-3143, file 1248.

Carroll, K. 2002. Windsor Causeway. Unpublished Factsheet. 2p.

CBCL Limited Consulting Engineers [CBCL]. 1994. Windsor wastewater collection and treatment strategy. Prepared for the Town of Windsor. Windsor, NS: CBCL.

CBCL. 2003. Mill Lakes Watershed assessment study. Prepared for the Town of Windsor. Windsor, NS: CBCL.

Chaput, G., and R.G. Bradford. 2003. American shad *(Alosa sapidissima)* in Atlantic Canada. DFO Canadian Science Advisory Secretariat Research Document 2003/009. 71p.

Clark, A.H. 1968. Acadia: the geography of early Nova Scotia to 1760. Madison, WI: University of Wisconsin Press. 450p.

Coker, G.A., C.B. Portt, and C.K. Minns. 2001. Morphological and ecological characteristics of Canadian freshwater fishes. Canadian Manuscript Report of Fisheries and Aquatic Sciences, 2554: 89p.

Committee on the Status of Endangered Wildlife in Canada [COSEWIC]. 2004a. Canadian species at risk, November 2004. Ottawa, ON: COSEWIC.

COSEWIC. 2004b. Detailed COSEWIC species assessments, November 2004. Ottawa, ON: COSEWIC.

Conrad, V. and R. Semple. 1987. Fish passage at Avon River Causeway and fish enhancement potential. Doc. no. 87-3. Unpublished Report. Halifax, NS: DFO. 29p.

Court of General Sessions of the Peace for Hants County (1812-1849). Public Archives of Nova Scotia, Halifax, Nova Scotia, RG 34-313, p.2.

Cowx, I.G. 2002. Chapter 17. Recreational fisheries. In P.J.B. Hart, and J.D. Reynolds (eds.), Handbook of Fish Biology and Fisheries, Volume 2: Fisheries. p. 367-390. Malden, MA: Blackwell Publishing.

Cunningham, F.H. 1909. Appendix No. 13. Fish breeding. In Forty-Second Annual Report of the Department of Marine and Fisheries 1908-9: Fisheries. p. 370-333. Ottawa, ON.

Daborn, G.R. 1997. Chapter 1. Fundy Marine Ecosystem Science Project: science overview. In J.A. Percy, P.G. Wells, and A.J. Evans (eds.), Bay of Fundy Issues: A Scientific Overview. Workshop Proceedings, Wolfville, Nova Scotia. January

29 to February 1, 1996. Environment Canada-Atlantic Region Occasional Report No. 8. p. 1-8. Sackville, NB: Environment Canada.

Daborn, G.R., M. Brylinsky, and K. Muschenheim. 2004. Fish populations and salt marsh productivity near the Windsor Causeway. Report prepared for the Nova Scotia Department of Transportation and Public Works. DRAFT. Wolfville, NS: Acadian Centre for Estuarine Research. 120p.

Davis, D., and S. Browne (eds.). 1997. Natural history of Nova Scotia. Volume 1: topics and habitats. Halifax, NS: Nova Scotia Museum and Nimbus Publishing. 518p.

Dawson, J.W. 1857. A handbook of the geography and natural history of the Province of Nova Scotia: for the use of schools, families and travellers. Fourth Edition. Pictou, NS. 95p.

Deal, M., and A. Butt. 1990. The St. Croix excavation, 1990. Ms. on File. Halifax, NS: Nova Scotia Museum.

Deemer, L., and B. Skelhorn. 1983. Letter from L. Deemer and B. Skelhorn, Residents of Windsor, to Department of Fisheries. Dated 3 August 1983. DFO, Bedford Institute of Oceanography [BIO], Dartmouth, NS, Causeway Files.

Department of Fisheries and Oceans [DFO]. 1968. Fisheries river basin study: Avon River, Nova Scotia. Paper #22 Prepared for the Atlantic Provinces Water Resource Study. Unpublished Report. DFO, BIO, Dartmouth, NS, Causeway Files.

DFO. 2003. Atlantic salmon Maritime Provinces overview for 2002. DFO Science. Stock Status Report 2003/026. 46p.

DFO. 2004. Allowable harm assessment for inner Bay of Fundy Atlantic salmon. DFO Canadian Science Advisory Secretariat Research Document 2004/030. 4p.

DFO Electro-fishing Surveys Database. DFO, Dartmouth, NS. Accessed in 2004.

Department of Marine and Fisheries [DMF]. 1879. Appendix No.13. Synopses of fishery overseers' reports in the Province of Nova Scotia, for the year 1878. In Appendix No. 1 to the Report of the Commissioner of Fisheries: Reports of Fishery Officers of the Dominion of Canada 1878. p. 234-248. Ottawa, ON.

DMF. 1880. Appendix No. 12. Synopses of fishery overseers' reports in the Province of Nova Scotia, for the year 1879. In Supplement No. 2 to the Eleventh Annual Report of the Minister of Marine and Fisheries for the Year 1879: Statements Connected with the Report of the Commissioner of Fisheries for the year 1879. p. 208-230. Ottawa, ON.

Dominion Commissioner of Fisheries. 1898. Letter to Mr. R. Hockin, Inspector. Dated 10 February 1898. National Archives of Canada, Ottawa, ON, RG23, vol.315, reel T-4000, file 2586.

Douglas, S.G., R.G. Bradford, and G. Chaput. 2003. Assessment of striped bass (*Morone saxatilis*) in the Maritime Provinces in the context of species at risk. DFO Canadian Science Advisory Secretariat Research Document 2003/008. 54p.

Downing, J.A., C. Plante, and S. Lalonde. 1990. Fish production correlated with primary productivity, not the morphoedaphic index. Canadian Journal of Fisheries and Aquatic Sciences, 47(10): 1929-1936.

Dunfield, R.W. 1985. The Atlantic salmon in the history of North America. Canadian Special Publication of Fisheries and Aquatic Sciences, 80: 181p.

Durbin, A.G., S.W. Nixon, and C.A. Oviatt. 1979. Effects of the spawning migration of the alewife, *Alosa pseudoharengus*, on freshwater ecosystems. Ecology, 60(1): 8-17.

Evans, D.O., K.H. Nicholls, Y.C. Allen, and M.J. McMurtry. 1996. Historical land use, phosphorus loading, and loss of fish habitat in Lake Simcoe, Canada. Canadian Journal of Fisheries and Aquatic Sciences, 53(Suppl.1): 194-218.

Fisher, W. 1923. Report of Ward Fisher, Chief Inspector, to W.A. Found, Esq., Director of Fisheries. Dated 3 December 1923. National Archives of Canada, Ottawa, ON, RG23, Acc. 80-1/260, vol. 801, file 719-3-11, pt. 2.

Fortin, R., M. Leveille, P. Laramee, and Y. Mailhot. 1990. Reproduction and year-class strength of the Atlantic tomcod (*Microgadus tomcod*) in the Sainte-Anne River, at La Perade, Quebec. Canadian Journal of Zoology, 68(7): 1350-1359.

Found, W.A. 1911. Letter from Wm. A. Found, Superintendent of Fisheries, to Robert Hockin, Esq., Inspector of Fisheries. Dated 8 February 1911. National Archives of Canada, Ottawa, ON, RG 23, vol. 225, reel T-3143, file 1248.

Found, W.A. 1912. Letter from W.A. Found, Superintendent of Fisheries, to R. Hockin, Inspector of Fisheries. Dated 27 May 1912. National Archives of Canada, Ottawa, ON, RG23, vol. 315, reel T-4000, file 2586.

Found, W.A. 1927. Letter from W.A. Found, Acting Deputy Minister of Fisheries, to C.H. Brown, Esq., Secretary, West Hants Fish, Game and Forest Protective Association. Dated 12 October 1927. National Archives of Canada, Ottawa, ON, RG 23, acc. 80-1/126, vol. 597, file 705-15-1, pt.1.

Gibson, A.J.F., P.G. Amiro, and K.A. Robichaud-Leblanc. 2003. Densities of juvenile Atlantic salmon (*Salmo Salar*) in inner Bay of Fundy rivers during 2000 and 2002 with reference to past abundance inferred from catch statistics and electrofishing surveys. Canadian Science Advisory Secretariat Research Document 2003/120. 29p.

Gibson, A.J.F., and R.A. Myers. 2003. Biological reference points for anadromous alewife (*Alosa pseudoharengus*) fisheries in the Maritime Provinces. Canadian Technical Report of Fisheries and Aquatic Sciences, 2468: 50p.

Gilpin, J.B. 1879. Art. VII - On the salmon of Nova Scotia. Proceedings and Transactions of the Nova Scotian Institute of Natural Sciences, 5: 39-47.

Government of Nova Scotia. 1816. Journal and Proceedings of the House of Assembly of the Province of Nova Scotia, 1816. Halifax, NS.

Grant, J.W.A, J. Englert, and B.F. Bietz. 1986. Application of a method for assessing the impact of watershed practices: effects of logging on salmonid standing crops. American Journal of Fisheries Management, 6: 24-31.

Haggan, N., J. Archibald, and S. Salas. 1998. Knowledge gains power when it is shared. In D. Pauly, T.J. Pitcher, and D. Preikshot (eds.). Back to the Future: Reconstructing the Strait of Georgia Ecosystem. Fisheries Centre Research Reports 6(5): 8-13.

Halliwell, D.B., R.W. Langdon, R.A. Daniels, J.P. Kurtenbach, and R.A. Jacobson. 1998. Classification of freshwater fish species of the northeastern United States for use in the development of indices of biological integrity, with regional applications. In T.P. Simon (ed.). Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. p. 301-337. Boca Raton, FL: CRC Press.

Hants' County Fishery Regulations, for 1843. In Court of General Sessions of the Peace for Hants County (1812-1849). Public Archives of Nova Scotia, Halifax, Nova Scotia, RG 34-313, p.2.

Hants' County Fishery Regulations, for 1852-3. In Court of General Sessions of the Peace for Hants County (1850-1860). Public Archives of Nova Scotia, Halifax, Nova Scotia, RG 34-313, p.4.

Haro, A., T. Castro-Santos, J. Noreika, and M. Odeh. 2004. Swimming performance of upstream migrant fishes in open-channel flow: a new approach to predicting passage through velocity barriers. Canadian Journal of Fisheries and Aquatic Sciences, 61(9): 1590-1601.

Harvey, J. 1997. Death watch on the Petitcodiac. Atlantic Salmon Journal, 46(2): 36-43.

Harvey, J., D. Coon and J. Abouchar. 1998. Habitat lost: taking the pulse of estuaries in the Canadian Gulf of Maine. Fredericton, NB: Conservation Council of New Brunswick. 81p.

Haverstock, M. 2004. An investigation into fish passage at the Avon River causeway. Unpublished Report. Truro, NS: Nova Scotia Department of Agriculture and Fisheries. 28p.

Hearn, W.E. 1987. Interspecific competition and habitat segregation among stream-dwelling trout and salmon: a review. Fisheries, 12(5): 24-31.

Helfield, J.M., and R.J. Naiman. 2001. Effects of salmon-derived nitrogen on riparian forest growth and implications for stream productivity. Ecology, 82(9): 2403-2409.

Hockin, R. 1894. Report of R. Hockin, Inspector, to Deputy Minister of Marine and Fisheries. Dated 15 May 1894. National Archives of Canada, Ottawa, ON, RG23, vol. 225, reel T-3143, file 1248.

Hockin, R. 1896. Report of Robert Hockin, Inspector of Fisheries, to Edward E Prince, Esq. Dated 29 July 1896. National Archives of Canada, Ottawa, ON, RG23, vol. 244, reel T-3164, file 1560, pt.1.

Hockin, R. 1897. Annual report on the fisheries of District No. 2, Nova Scotia, comprising the counties of Cumberland, Colchester, Pictou, Antigonish, Guysborough, Halifax, and Hants, for the year 1895, by Inspector Robt. Hockin. In Twenty-Ninth Annual Report of the Department of Marine and Fisheries 1896: Fisheries. p. 49-54. Ottawa, ON.

Hockin, R. 1901. Annual report on the fisheries of District No. 2, of Nova Scotia, comprising the counties of Antigonish, Colchester, Cumberland, Guysboro’, Halifax, Hants and Pictou. In Thirty-Third Annual Report of the Department of Marine and Fisheries 1900: Fisheries. p. 41-45. Ottawa, ON.

Hockin, R. 1902. Annual report on the fisheries of District No. 2, of Nova Scotia, comprising the counties of Antigonish, Colchester, Cumberland, Guysboro’, Halifax, Hants and Pictou. In Thirty-Fourth Annual Report of the Department of Marine and Fisheries 1901: Fisheries. p. 41-46. Ottawa, ON.

Hockin, R. 1911. Report of R. Hockin, Inspector, to Deputy Minister of Marine and Fisheries. Dated 25 May 1911. National Archives of Canada, Ottawa, ON, RG 23, vol. 225, reel T-3143, file 1248.

Hockin, R. 1914. Letter from R. Hockin, to Deputy Minister of Marine and Fisheries. Dated 11 May 1914. National Archives of Canada, Ottawa, ON, RG 23, vol. 315, reel T-4000, file 2586.

Hollingsworth, S. 1787. The present state of Nova Scotia with a brief account of Canada and the British islands on the coast of North America. Edinburgh, Scotland. 221p.

Hubley, P. 2003. Letter from Philip Hubley, Head, Engineering Services, Diadromous Fish Division, to Mr. Hank Kolstee, Nova Scotia Department of Agriculture and Fisheries. “Re: Operating Regime for Avon Causeway Tidal Gates during Peak Spring Migration of Diadromous Fish”. Dated 6 May 2003. DFO, BIO, Dartmouth, NS, Causeway Files.

Hynes, H.B.N. 1970. The ecology of running waters. Toronto, ON: University of Toronto Press. 555p.

Isaacman, L., and K. Beazley. 2005. Historic characterization of changes to the fish community in the Avon River, Nova Scotia. In J.A. Percy, A.J. Evans, P.G. Wells, and S.J. Rolston (eds.), The Changing Bay of Fundy: Beyond 400 Years. Proceedings of the 6th Bay of Fundy Workshop, Cornwallis, Nova Scotia – September 29th – October 2nd, 2004. Environment Canada – Atlantic Region, Occasional Report No. 23. p. 189-197. Dartmouth, NS and Sackville, NB: Environment Canada. 480p.

Jansen, H. 1987. Letter from H. Jansen, Head, Engineering Services Section, Enhancement, Culture and Anadromous Fisheries Division, Department of Fisheries and Oceans, to Garry Rice, Manager, Hydro Production, Nova Scotia Power Corporation. “Re: Pesaquid Lake Water Levels, Avon River, Hants Co., N.S”. Dated 8 May 1987. DFO, BIO, Dartmouth, NS, Causeway Files.

Jessop, B.M. 1990. Stock-recruitment relationships of alewives and blueback herring returning to the Mactaquac Dam, Saint John River, New Brunswick. North American Journal of Fisheries Management, 10(1): 19-32.

Jessop, B.M. 1993. The status of rainbow smelt stocks in Scotia Fundy Region as indicated by catch and license statistics. DFO Atlantic Fisheries Research Document 93/69. 5p.

Jessop, B.M. 1999. The status (1960-1997) of alewife and blueback herring stocks in the Scotia-Fundy area as indicated by catch-effort statistics. Canadian Stock Assessment Secretariat Research Document 99/117. 22p.

Jessop, B.M. 2000. Underwater world—American eel. Ottawa, ON: DFO. 8p.

Jessop, B.M., and H.A. Parker. 1988. The alewife in the Gaspereau River, Kings County, Nova Scotia, 1982-1984. Canadian Manuscript Report of Fisheries and Aquatic Sciences, 1992: 34p.

Johannes, R.E., M.M.R. Freeman, and R.J. Hamilton. 2000. Ignore fishers’ knowledge and miss the boat. Fish and Fisheries, 1(3): 257-271.

Kaiser, M.J., and S. Jennings. 2002. Chapter 16. Ecosystem effects of fishing. In P.J.B. Hart, and J.D. Reynolds (eds.), Handbook of Fish Biology and Fisheries, Volume 2: Fisheries. p. 342-366. Malden, MA: Blackwell Publishing.

Kanno, Y. 2002. Fish community changes in River Philip, Nova Scotia and an index of sustainable coldwater streams. MES Thesis, Dalhousie University, Halifax, NS. 109p.

Kanno, Y., and K. Beazley. 2004. Freshwater fish consideration for aquatic fish conservation systems planning in Nova Scotia. Proceedings of the Nova Scotian Institute of Science, 42(2): 375-391.

Kanno, Y., and J. MacMillan. 2004. Developing an index of sustainable coldwater streams using fish community attributes in River Philip, Nova Scotia. Proceedings of the Nova Scotian Institute of Science, 42(Part 2): 319-338

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication, 5: 28p.

Kelso, J.R.M., R.J. Steedman, and S. Stoddart. 1996. Historical causes of change in Great Lakes fish stocks and the implications for ecosystem rehabilitation. Canadian Journal of Fisheries and Aquatic Sciences, 53(Suppl. 1): 10-19.

Knight, T.F. 1867. The river fisheries of Nova Scotia. Halifax, NS. 49p.

Kolstee, H. 2003. Avon River Causeway. Unpublished Document. 6p.

Lamothe, P.J., M. Gallagher, D.P. Chivers, and J.R. Moring. 2000. Homing and movement of yellow-phase American eels in freshwater ponds. Environmental Biology of Fishes, 58(4): 393-399.

Lawrence, F. 2004. Dalhousie Student Involved in Avon River Research Project. Hants Journal. 9 June 2004: 8.

Leim, A.H. 1924. The life history of the shad (*Alosa sapidissima* (Wilson)) with special reference to the factors limiting its abundance. Contributions to Canadian Biology 2(11): 161-284.

Leggett, W.C., and R.N. O'Boyle. 1976. Osmotic stress and mortality in adult American shad during transfer from saltwater to freshwater. Journal of Fisheries Biology, 8(6): 459-469.

Letters to DFO from Concerned Citizens. 1987. DFO, BIO, Dartmouth, NS, Causeway Files.

Lichatowich, J., L. Mobrand, and L. Lestelle. 1999. Depletion and extinction of Pacific salmon (*Oncorhynchus spp.*): a different perspective. ICES Journal of Marine Science, 56(4): 467-472.

Loesch, J.G. 1987. Overview of life history aspects of anadromous alewife and blueback herring in freshwater habitats. American Fisheries Symposium 1: 89-103.

Loomer, L.S. 1996. Windsor, Nova Scotia: a journey in history. Windsor, NS: West Hants Historical Society. 399p.

Lucas, K.C. 1968. Memorandum to the Minister. “Re: Proposed Avon River Barrier”. Dated 2 April 1968. DFO, BIO, Dartmouth, NS, Causeway Files.

Lyons, J., L. Wang, and T.D. Simonson. 1996. Development and validation of an index of biotic integrity for coldwater streams in Wisconsin. North American Journal of Fisheries Management, 16(2): 241-256.

MacEachern, N. 1965. Letter N. MacEachern, Fish Culture Branch, to Mr. A.W. Wigglesworth, General Manager, Nova Scotia Water Authority. Dated 19 May 1965. DFO, BIO, Dartmouth, NS, Causeway Files.

MacEachern, N. 1968. Memorandum. “Re: Avon River causeway”. Dated 1 November 1968. DFO, BIO, Dartmouth, NS, Causeway Files.

Mackinson, S., and L. Nottestad. 1998. Combining local and scientific knowledge. Reviews in Fish Biology and Fisheries, 8(4): 481-490.

Maitland, P.S. 1995. The conservation of freshwater fish: past and present experience. Biological Conservation, 72(2): 259-270.

Mailhot, J. 1994. Traditional ecological knowledge: the diversity of knowledge systems and the study. Montreal, QC: Great Whale Environmental Assessment. 50p.

Maritime Marshland Rehabilitation Administration [MMRA]. 1965. Preliminary study Avon River Causeway. Amherst, NS: Nova Scotia Department of Forestry. 15p.

McDougall, D. 1898. Letter to Hon. Dr. Healy, MP. Dated 1 February 1898. National Archives of Canada, Ottawa, ON, RG23, vol. 315, reel T-4000, file 2586.

McDowall, R.M. 1988. Diadromy in fishes: migrations between freshwater and marine environments. London: Croom Helm. 308p.

McDowall, R.M. 1996. Diadromy and the assembly and restoration of riverine fish communities: a downstream view. Canadian Journal of Fisheries and Aquatic Sciences, 53(Suppl. 1): 219-236.

McInerney, J.E. 1964. Salinity preference: an orientation mechanism in salmon migration. Journal of the Fisheries Research Board of Canada, 21: 995-1018.

McLusky, D.S. 1989. The estuarine ecosystem. New York: Chapman and Hall. 215p.

Melvin, G.D., M.J. Dadswell, and J.D. Martin. 1985. Impact of lowhead hydroelectric tidal power development on fisheries. 1. A pre-operation study of the spawning population of American shad, *Alosa sapidissima* (Pisces:Clupeidae), in the Annapolis River, Nova Scotia, Canada. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1340. 33p.

Melvin, G.D., M.J. Dadswell, and J.D. Martin. 1986. Fidelity of American shad, *Alosa sapidissima* (Clupeidae), to its river of previous spawning. Canadian Journal of Fisheries and Aquatic Sciences 43(3): 640-646.

Metcalfe, J., G. Arnold, and R. McDowall. 2002. Chapter 8. Migration. In P.J.B. Hart, and J.D. Reynolds (eds.), Handbook of Fish Biology and Fisheries, Volume 1: Fish Biology. p. 176-199. Malden, MA: Blackwell Publishing.

Miller, R.R., J.D. Williams, and J.E. Williams. 1989. Extinctions of North American fishes during the past century. Fisheries, 14(6): 22-38.

Miller, V.P. 1993. The Micmac: A Maritime woodland group. In R.B. Morrison, and C.R. Wilson (eds.), Native peoples: The Canadian experience. p. 324-352. Toronto, ON: McClelland and Stewart Inc.

Mills, D. 1991. Ecology and management of Atlantic salmon. London: Chapman and Hall.

Mills, E.L., R. O'Gorman, J. DeGisi, R.F. Heberger, and R.A. House. 1992. Food of the alewife (*Alosa pseudoharengus*) in Lake Ontario before and after the establishment of *Bythotrephes cederstroemi*. Canadian Journal of Fisheries and Aquatic Sciences, 49(10): 2009-2019.

Moyle, P.B., and R.A. Leidy. 1992. Loss of biodiversity in aquatic ecosystems: evidence from fish faunas. In P.L. Fiedler and S.K. Jain (eds.), Conservation Biology: The Theory and Practice of Nature Conservation, Preservation and Management. p. 127-169. New York: Chapman and Hall.

Myers, G.S. 1949. Usage of anadromous, catadromous and allied terms for migratory fishes. Copeia, 1949: 89-97.

Nash, R.J., and F.L. Stewart. 1990. Melanson: a large Micmac village in Kings County, Nova Scotia. Curatorial Report No. 67. Halifax, NS: Nova Scotia Museum.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries, 16(2): 4-21.

Neis, B., D.C. Scneider, L. Felt, R.L. Haedrich, J. Fischer, and J.A. Hutchings. 1999. Fisheries assessment: what can be learned from interviewing resource users? Canadian Journal of Fisheries and Aquatic Sciences, 56(10): 1949-1963.

New Brunswick Department of Supply and Services (NBDSS). 2004. Status and modelling workshop summary Moncton NB, November 6, 2004. Petitcodiac Environmental Impact Assessment Website. <http://www.petitcodiac.com/statusModellingWorkshopSummary.htm>. Accessed 28 February 2004.

Niles, E. 2001. Review of the Petitcodiac River Causeway and fish passage issues. Paper prepared for the Minister of Fisheries and Oceans. Cap-Pelé, NB: DFO.

Northcote, T.G. 1967. The relation of movements and migrations to production in freshwater fishes. In S.D. Gerking (ed.), The Biological Basis of Freshwater Fish Production. p. 315-344. New York: Wiley.

Nova Scotia Department of Agriculture and Fisheries [NSDAF]. 2001a. Species sheets: inland. Speckled trout *(salvelinus fontinalis).* <http://www.gov.ns.ca/nsaf/sportfishing/species/spec.htm>. Accessed October 10, 2004.

NSDAF. 2001b. Species sheets: inland. Rainbow smelt *(Osmerus mordax).* <http://www.gov.ns.ca/nsaf/sportfishing/species/smel.htm>. Accessed October 14, 2004.

NSDAF. 2004a. Avon River Watershed Final Report. Unpublished Manuscript. 37p.

NSDAF. 2004b. Smallmouth bass distributions in Nova Scotia January 2004. Unpublished Database.

Nova Scotia Department of Agriculture and Marketing [NSDAM]. 1987. Maritime dykelands: the 350 year struggle. Halifax, NS: Province of Nova Scotia and NSDAM. 110p.

Nova Scotia Department of Natural Resources [NSDNR]. 2002. General status ranks of wild species in Nova Scotia. <http://www.gov.ns.ca/natr/wildlife/genstatus/ranks.asp>. Accessed 23 February 2005.

Nova Scotia Golf Association History Committee. 2004. Avon Valley Golf & Country Club course history. <http://www.avonvalleygolf.com/>. Accessed 23 February 2005.

Pace, M.L., J.J. Cole, S.R. Carpenter, and J.F. Kitchell. 1999. Trophic cascades revealed in diverse ecosystems. Trends in Ecology and Evolution, 14(12): 483-488.

Percy, J.A. 1997. Chapter 5. Marine resources of the Bay of Fundy. In J.A. Percy, P.G. Wells, and A.J. Evans (eds.), Bay of Fundy Issues: A Scientific Overview. Workshop Proceedings, Wolfville, Nova Scotia. January 29 to

February 1, 1996. . Environment Canada-Atlantic Region Occasional Report No. 8. p. 103-137. Sackville, NB: Environment Canada.

Percy, J.A., and P.G. Wells. 1997. Chapter 6. Bay of Fundy ecosystem issues: a summary. In J.A. Percy, P.G. Wells, and A.J. Evans (eds.), Bay of Fundy Issues: A Scientific Overview. Workshop Proceedings, Wolfville, NS, January 29 to February 1, 1996. Environment Canada – Atlantic Region Occasional Report No. 8. p. 139-150. Sackville, NB: Environment Canada.

Perley, M.H. 1852. Reports on the Sea and River Fisheries of New Brunswick. Fredericton, NB. 294p.

Persson, L. 2002. Chapter 15. Community ecology of freshwater fishes. In P.J.B. Hart, and J.D. Reynolds (eds.), Handbook of Fish Biology and Fisheries. Volume 1: Fish Biology. p. 321-340. Malden, MA: Blackwell Publishing.

Pesch, C.E., and J. Garber. 2001. Historical analysis, a valuable tool in community-based environmental protection. Marine Pollution, 42(5): 339-349.

Peterson, R.H., and D. Gale. 1991. Fish species associations in riffle habitat of streams of varying size and acidity in New Brunswick and Nova Scotia. Journal of Fish Biology, 38(6): 859-871.

Peterson, R.H., P.H. Johansen, and J.L. Metcalfe. 1980. Observations on early life stages of Atlantic tomcod, *Microgadus tomcod*. Fisheries Bulletin, 78(1): 147-158.

Pitcher, T.J. 1998. “Back to the Future”: a novel methodology and policy goal in fisheries. In D. Pauly, T.J. Pitcher and D. Preikshot (eds.), Back to the Future: Reconstructing the Strait of Georgia Ecosystem. Fisheries Centre Research Reports 6(5): 4-7.

Policansky, D. 2002. Catch and release recreational fishing: a historical perspective. In T.J. Pitcher and C. Hollingworth (eds), Recreational Fisheries: Ecological, Economic and Social Evaluation. Fish and Aquatic Resources Series 8. p. 74-94. Ames, IA: Blackwell Science.

Post, J.R., M. Sullivan, S. Cox, N.P. Lester, C.J. Walters, E.A. Parkinson, A.J. Paul, L. Jackson, and B.J. Shuter. 2002. Canada’s recreational fisheries: the invisible collapse? Fisheries, 27(1): 6-17.

Preikshot, D. 1998. Using interdisciplinary data in fisheries science. In D. Pauly, T.J. Pitcher and D. Preikshot (eds.), Back to the Future: Reconstructing the Strait of Georgia Ecosystem. Fisheries Centre Research Reports 6(5): 14-18.

Prince, E.E. 1899. Special appended reports 1898. 1. Fluctuations in the abundance of fish. In Thirty-First Annual Report of the Department of Marine and Fisheries 1898: Fisheries. p. 5-21. Ottawa, ON.

Prince, E.E. 1901. Memorandum “re: Sawdust pollution in Hants County, NS”. Dated 18 December 1901. National Archives of Canada, Ottawa, ON, RG23, vol. 315, reel T-4000, file 2586.

Prince, E.E. 1903. Special appended reports 1902. 2. The fish-way problem. In Thirty-Fifth Annual Report of the Department of Marine and Fisheries 1902: Fisheries. p. lxi-lxxxi. Ottawa, ON.

Prince, E.E. 1906. Appendix No. 11. Report on fish-breeding operations in Canada 1905. In Thirty-Ninth Annual Report of the Department of Marine and Fisheries 1906: Fisheries. p. 225-272. Ottawa, ON.

Prince, E.E. 1910. Dominion shad fishery commission 1908-1910. Report and recommendations, with interim report, précis of evidence and seven appendices. Ottawa, ON: Government Printing Bureau. 115p.

Public Archives of Nova Scotia. 1933. Report of the Nova Scotia Archives. In Journal and Proceedings of the House of Assembly for the Province of Nova Scotia, Session 1933. Halifax, NS: Queen’s Printer.

Rand, S.T. 1875. A first reading book in the Micmac language: comprising the Micmac numerals, and the names of the different kinds of beasts, birds, fishes, trees, &c. of the maritime provinces of Canada. Also, some of the Indian names of places, and many familiar phrases, translated literally into English. Halifax, NS.

Redmond, L.C., S. Filipek, N. Foster, A. Kapuscinski, B Knuth, D. McEwan, T. Nesler, K. Pereira, and S. Solarz. 1999. Responsible use of fish and other aquatic organisms. Position statement. Fisheries, 24(1): 30-35.

Reynolds, J.D., N.K. Dulvy, and C.M. Roberts. 2002. Chapter 15. Exploitation and other threats to fish conservation. In P.J.B. Hart, and J.D. Reynolds (eds.), Handbook of Fish Biology and Fisheries. Volume 2: Fisheries. p. 319-341. Malden, MA: Blackwell Publishing.

Richter, B.D., D.P. Braun, M.A. Mendelson, and L.L. Master. 1997. Threats to imperilled freshwater fauna. Conservation biology, 11(5): 1081-1093.

Robertson, M., P. Nichols, P. Horwitz, K. Bradby, and D. MacKintosh. 2000. Environmental narratives and the need for multiple perspectives to restore degraded landscapes in Australia. Ecosystem Health, 6(2): 119-133.

Robinson, M., and S.C. Courtenay. 1999. Genetic investigations on striped bass (*Morone saxatilis*) in the Canadian Maritime provinces. DFO Canadian Stock Assessment Secretariat Research Document 99/006. 23p.

Rodd, J.A. 1915. Appendix No. 13. Fish breeding. In Forty-Seventh Annual Report of the Department of Marine and Fisheries 1913-14: Fisheries. pg.307-342. Ottawa, ON.

Rodd, J.A. 1916. Appendix No. 11. Fish breeding. In Forty-Eighth Annual Report of the Fisheries Branch-Department of the Naval Service 1914-15. p. 308-342. Ottawa, ON.

Rodd, J.A. 1929. Appendix No. 3. Fish culture annual report by J.A. Rodd, Director. In Sixty-Second Annual Report of the Fisheries Branch, Department of Marine and Fisheries, for the Year 1928-29. p. 140-209. Ottawa, ON.

Rodd, J.A. 1930. Appendix No. 3. Fish culture annual report by J.A. Rodd, Director. In Sixty-Third Annual Report of the Fisheries Branch, Department of Marine and Fisheries, for the Year 1929-30. p. 167-242. Ottawa, ON.

Rogers, W.H. 1879. Appendix No. 11. Report of W.H. Rogers, Esq., Fishery Officer for Nova Scotia on the state and condition of fishways in Nova Scotia during the season of 1878. In Supplement No.4 to the Eleventh Annual Report of the Minister of Marine and Fisheries for the Year, 1878: Report of the Commissioner of Fisheries for the Year Ending 31st December, 1878. p.176-181. Ottawa, ON.

Rogers, W.H. 1881. Appendix No. 9. Report of W.H. Rogers, Esq., Inspector of Fisheries for the Province of Nova Scotia, with statistics of fisheries. In Supplement No.2 to the Thirteenth Annual Report of the Minister of Marine and Fisheries for the Year 1880: Fisheries Statements for the Year 1880. p. 142-205. Ottawa, ON.

Rogers, W.H. 1886. Appendix No. 3. Annual report of the fisheries of Nova Scotia for the year 1885, by W.H. Rogers, Esq., Inspector. In Annual Report of the Department of Fisheries, Dominion of Canada for the Year 1885. p. 83-98. Ottawa, ON.

Rogers, W.H. 1887. Appendix No. 3. Annual report on the fisheries of Nova Scotia for the year 1886, by W.H. Rogers, Esq., Inspector. In Annual Report of the Department of Fisheries, Dominion of Canada, for the Year 1886. p. 83-95. Ottawa, ON.

Rulifson, R.A., and M.J. Dadswell. 1995. Life history and population characteristics of striped bass in Atlantic Canada. Transactions of the American Fisheries Society, 124(4): 477-507.

Rulifson, R.A., and K.A. Tull. 1999. Striped bass spawning in a tidal bore river: the Shubenacadie Estuary, Atlantic Canada. Transactions of the American Fisheries Society, 128(4): 613-624.

Ruggles, C.P. 1969. Letter from C.P. Ruggles, Chief, to Mr. Merrill Prime, Director, Wildlife Conservation. Dated 15 August 1969. DFO, BIO, Dartmouth, NS, Causeway Files.

Ryder, R.A., and S.R. Kerr. 1989. Environmental priorities: placing habitat in hierarchic perspective. In C.D. Levings, L.B. Holtby and M.A. Henderson (eds.), Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. P. 2-12. Canadian Special Publications of Fisheries and Aquatic Sciences, 105.

Salter, R.J.U. 1915. Extract from the report of overseer R.J.U. Salter, Newport, N.S., for week ended Aug. 28, 1915. National Archives of Canada, Ottawa, ON, RG 23, acc. 80-1/260, vol. 710, file 715-4-1- pt.1.

Sangster, C.W. 1994. An environmental report on the Windsor mudflats. Unpublished Document. 58p.

Scott, W.B and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin, 183: 966p.

Scott, W.B., and M.G. Scott. 1988. Atlantic fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences, 219: 731p.

Shand, G.V. 1979. Historic Hants County. Halifax, NS: G.V. Shand. 167p.

Shanks, J.T. 1994. ‘Equivocation, procrastination, evasion and subterfuge’: the Avon River Power Company confronts the Public Utilities Commission, 1921-22. B.A. Honours Thesis, Acadia University, Wolfville, NS. 90p.

Sheldon, A.L. 1988. Conservation of stream fishes: patterns of diversity, rarity, and risk. Conservation Biology, 2(2): 149-156.

Smith, K.E.H. 1965. Memorandum from K.E.H. Smith, Biologist, to C.P. Ruggles, Chief Biologist. “Re: Avon River Causeway-Crossing”. Dated 11 May 1965. DFO, BIO, Dartmouth, NS, Causeway Files.

Smith, T.I.J., and J.P. Clugston. 1997. Status and management of Atlantic sturgeon, *Acipenser oxyrinchus*, in North America. Environmental Biology of Fishes, 48: 335-346.

Steedman, R.J., T.H. Whillans, A.P. Behm, K.E. Bray, K.I. Cullis, M.M. Holland, S.J. Stoddart, and R.J. White. 1996. Use of historical information for conservation and restoration of Great Lakes aquatic habitat. Canadian Journal of Fisheries and Aquatic Sciences, 53(Suppl. 1): 415-423.

Stewart, L.L., and P.J. Auster. 1987. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic)--Atlantic tomcod. U.S. Fish and Wildlife Service Biological Report, 82(11.76). 8p.

Stockner, J.G., and E.A. MacIsaac. 1996. British Columbia lake enrichment programme: two decades of habitat enhancement for sockeye salmon. Regulated Rivers: Research and Management, 12(4-5): 547-461.

Stokesbury, K.D., and M.J. Dadswell. 1989. Seaward migration of juveniles of three herring species, *Alosa*, from an estuary in the Annapolis River, Nova Scotia. Canadian Field-Naturalist, 103(3): 388-393.

Sutherland, D.H. 1935. Letter from D.H. Sutherland, Chief Supervisor, to W.A. Found, Deputy Minister, Department of Fisheries. Dated 11 September 1935. National Archives of Canada, Ottawa, ON, RG23, acc. 71/324, vol. 434, file 702-2-4.

Thorpe, J.E. 1994. Significance of straying in salmonids and implications for ranching. Aquaculture and Fisheries Management, 25 (Suppl. 2): 183–190.

Towers, J. 1995. Wildlife of Nova Scotia. Halifax, NS: Nimbus Publishing and Nova Scotia Department of Natural Resources.

Venning, W.H. 1869. Appendix No. 3. Report of W.H. Venning, Esquire, Inspector of Fisheries, New Brunswick and Nova Scotia. In Annual Report of the Department of Marine and Fisheries for the year 1868. p. 18-35. Ottawa, ON.

Vieth, F.H.D. 1868. Brief report on the condition of the principal rivers on the south coast of Nova Scotia. Halifax, NS: Compton & Co. 16p.

Vieth, F.H.D. 1884. An address of the senate, dated 22nd February, 1884;-for copies of all reports made to the Department of Marine and Fisheries, between the 1st of March, 1881, and the last day of December, 1882, by F.N.D. Veith, Esq., an officer appointed to inspect and report upon the condition of the rivers in Nova Scotia, and to perform other duties in connection with the fisheries in that Province. Paper No. 134. In Dominion of Canada, Second Session of the Fifth Parliament of the Dominion of Canada, Session 1884, 17(11).

Waldman, J.R., and I.I. Wirgin. 1998. Status and restoration options for Atlantic sturgeon in North America. Conservation Biology 12(3): 631-638.

Warren, M. L., and B. M. Burr. 1994. Status of freshwater fishes of the United States: overview of an imperiled fauna. Fisheries, 19(1): 6-18.

Waters, T.F. 1983. Replacement of brook trout by brown trout over 15 years in a Minnesota stream: production and abundance. Transactions of the American Fisheries Society, 112: 137-146.

Waters, T.F. 1995. Sediment in streams: sources, biological effects, and control. American Fisheries Society Monograph, 7: 251 p.

Watt, W., C. Scott, and W. White. 1983. Evidence of acidification of some Nova Scotian rivers and its impact on Atlantic salmon, *Salmo salar*. Canadian Journal of Fisheries and Aquatic Sciences, 40(4): 462-473.

Wells, P.G. 1999. Environmental impact of barriers on rivers entering the Bay of Fundy: report of an ad hoc Environment Canada working group. Technical Report Series No. 334. Ottawa, ON: Canadian Wildlife Service. 43p.

White, P.S., and J.L. Walker. 1997. Approximating nature's variation: selecting and using reference information in restoration ecology. Restoration ecology, 5: 338-349.

Wildlife Habitat and Watercourses Protection Regulations, N.S. Reg. 166/2002

Williams, R.R., and G.R. Daborn. 1984. Spawning of the American shad (*Alosa sapidissima*) in the Annapolis River, Nova Scotia. Proceedings of the Nova Scotia Institute of Science, 34(1): 9-14.

Willson, M.F., and K.C. Halupka. 1995. Anadromous fish as keystone species in vertebrate communities. Conservation Biology, 9(3): 489-497.

Wilmot, S. 1887. Report on fish-breeding in the Dominion of Canada 1886. In Annual Report of the Department of Fisheries, Dominion of Canada, for the Year 1886. Ottawa, ON.

Wirgin, I.I., B. Jessop, S. Courtenay, M. Pedersen, S. Maceda, and J.R. Waldman. 1995. Mixed-stock analysis of striped bass in two rivers of the Bay of Fundy as revealed by mitochondrial DNA. Canadian Journal of Fisheries and Aquatic Sciences, 52(5): 961-970.

World Wildlife Fund. 2001. The status of wild Atlantic salmon: a river by river assessment. World Wildlife Fund.