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REVIEW OF EXISTING SCIENTIFIC LITERATURE PERTAINING TO FISH MORTALITY AND ITS POPULATION-LEVEL IMPACTS AT THE ANNAPOLIS TIDAL HYDROELECTRIC GENERATING STATION, ANNAPOLIS ROYAL, NOVA SCOTIA

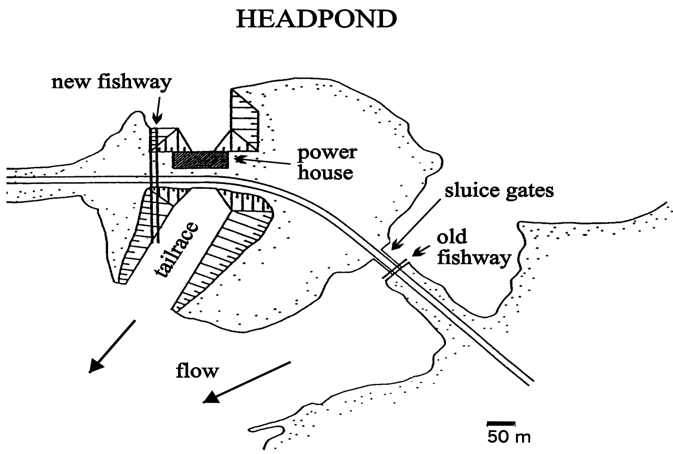

Figure 1. The Annapolis Tidal Generating Station in Annapolis Royal, Nova Scotia (from Gibson 1996b, adapted from Ruggles and Stokesbury 1990).

Context:

The Annapolis Tidal Generating Station (Annapolis TiGS) is located in the Annapolis River estuary in Annapolis Royal, Nova Scotia, Canada. It has been in operation since 1985. It is the first tidal hydroelectric generating station constructed in North America.

The operation of the Annapolis TiGS is known to cause mortality of some fish within the Annapolis River estuary, and there is potential for these mortalities to have population-level effects. Fisheries and Oceans Canada (DFO) Ecosystem Management Branch requested that a review of existing scientific literature pertaining to the Annapolis TiGS be undertaken to provide a better understanding of whether the current operation of the TiGS is in compliance with the Fisheries Act *and the* Species at Risk Act*. The objectives of this report, undertaken to fulfill this request, are to provide an evaluation of the published information about the fish community in the vicinity of the Annapolis TiGS, fish passage and fish mortality at the Annapolis TiGS, and population-level impacts associated with this mortality. The information in this report is intended to inform regulatory decisions under the* Fisheries Act *and* Species at Risk Act*.*

This Science Advisory Report is from the January 9-10 and March 6, 2019 Review of Existing Scientific Literature to Determine the Level of Fish Mortality and Potential Impacts on Fish Populations as a result of the Operation of the Annapolis Tidal Power Facility. Additional *publications from this meeting will be posted on the Fisheries and Oceans Canada Science Advisory Schedule as they become available.*

SUMMARY

- The purpose of this advisory process was to provide a summary and evaluation of the scientific literature pertaining to the mortality of fish at the Annapolis Tidal Generating Station (Annapolis TiGS) and the population-level impacts associated with this mortality.
- Research at the Annapolis TiGS is dated. The most recent field study at the TiGS identified during this review occurred in 1999. The most recent assessment of changes in life-history characteristics, for American Shad, occurred in 1996.
- There is a diverse fish community present at the Annapolis TiGS. At least forty species have been captured in studies at or near the station. Abundance of each species is not known, although based on sampling in the 1990s, the number of fish moving past the causeway annually would be expected to be in the low millions. Many of these fish are small, including Atlantic Silversides, and young-of-the-year Atlantic Herring, Blueback Herring, Alewife and American Shad.
- The highest priority species for determining population-level impacts are those with COSEWIC designations as extirpated, endangered, threatened, or special concern; and those that support commercial, recreational and aboriginal (CRA) fisheries for which the expected population-level impact, based on a qualitative assessment of the risk associated with the passage at the Annapolis TiGS, is a reduction in abundance greater than 10.
- There are eight species that were identified in studies in the Annapolis River and estuary that have been designated as extirpated, endangered, threatened, or special concern by COSEWIC. These are: American Eel, Atlantic Salmon, Atlantic Sturgeon, Atlantic Wolffish, White Hake (hake at Annapolis were not typically identified to species), Lumpfish, Spiny Dogfish and Striped Bass. Of these species, only Atlantic Wolffish is listed under the Species at Risk Act, but listing decisions are pending for other species.
- Additional species that support CRA fisheries for which the risk was scored as an abundance decline >10% are: Alewife, American Shad, Atlantic Menhaden, Blueback Herring and Rainbow Smelt.
- There is evidence that mortality of fish occurs at the Annapolis TiGS. This evidence includes: anecdotal reports of dead fish (with injuries consistent with turbine passage) in the vicinity of the Annapolis TiGS, observations of dead fish downstream of the turbine, and in-situ research about survival of fish passing through the turbine.
- There are three routes of passage for fish moving downstream at the Annapolis TiGS: the new fishway, the old fishway and through the turbine tube. Studies of fishway utilization are limited to the summer and fall. Studies do not include larger fish not susceptible to capture in one-meter-diameter nets. Overall, with the exception of Atlantic Silverside, the studies indicate that the majority of fish pass through the turbine.
- There are three studies that provide turbine mortality rate estimates for fish that pass through the turbine. All are limited to quantifying mortality occurring during or shortly after fish passage.
- When interpreting the turbine mortality rate estimates, it is important to remember that the turbine mortality rate alone does not determine the impact on the population. First, if some portion of the population move past the causeway via the fishways, overall survival will be higher than what is implied by the turbine mortality rate. Second, if fish move back and forth

past the causeway more than one time, they may pass through the turbine more than one time leading to lower overall survival.

- Many of the biases associated with turbine mortality rate studies lead to single-pass estimates that are biased high (i.e. turbine mortality rates that are over-estimated).
- A study for adult American Shad in 1986 concluded that 21.3% (90% confidence interval +/- 15.2%) of these fish passing through the turbine die as a result of passage.
- A study in 1999 to trial a new method of estimating turbine mortality rates provided estimates for 12 species of fish. These estimates ranged from 0.0% for Sea Lamprey to 23.4% (95% confidence interval: 6.1% to 58.8%) for young-of-the-year American Shad. These estimates may be biased high because they do not fully account for capture and handling mortality.
- Fish diversion systems, intended to deter fish from passing through the turbine can be either physical or behavioral. Physical barriers have been considered impractical at the Annapolis TiGS due to its large size, debris, and the small size of most fish.
- Behavioral guidance systems have been tested at the Annapolis TiGS, and have shown promise for young-of-the-year American Shad, Alewife and Blueback Herring. Further refinement of the system would likely improve the effectiveness for these species. Whether a behavioral guidance system can be developed that would be effective for all species at the Annapolis TiGS is not known but is unlikely.
- The Annapolis River American Shad population is the only population for which a comparison of their biological characteristics before and after Annapolis TiGS became operational is available.
- Comparison of the characteristics of the American Shad spawning run before and after the turbine came online indicate a decline in the mean size, mean age, maximum observed age, age-at-maturity, and percent of repeat spawners, and an overall increase in the total mortality rate. The direction of these changes is consistent with increased mortality at the Annapolis TiGS. However, the changes cannot be wholly attributed to the turbine without information about fishway usage, the expected number of passes through the turbine each year, and knowledge of other changes that would affect their survival that may have occurred during the 15 years over which these assessments occurred.
- Both genetic and tagging studies have shown that Striped Bass undergo coastal migrations and forage in estuaries other than those at the mouths of their natal rivers. The Striped Bass assemblage in the Annapolis River estuary, at least historically, consisted of fish from more than one population, the relative abundances of which likely changed through time and are not known. This, and the paucity of information about the rates of mortality of Striped Bass moving past the causeway, precludes an evaluation of the population-level effect of the Annapolis TiGS on the Annapolis River Striped Bass population.
- There is weak evidence that there may presently be a population of Atlantic Sturgeon native to the Annapolis River, but its status is not definitively known. If sturgeon encountering Annapolis TiGS are from other populations, the effect on those populations is likely quite low. However, if there is a population native to the Annapolis River, the effects of turbine mortality on a native population would be high.
- Data gaps for estimating population-level impacts of the Annapolis TiGS for the majority of species include: the proportion of populations that would be expected to encounter the turbine; rates of fishway usage and survival; survival of fish of all life stages that pass through the turbine; the expected number of passes through the turbine; and rates of other human-induced mortality.

- Development of reference mortality rates associated with passage at the Annapolis TiGS would help ensure that mortality rates are consistent with DFO's sustainable fisheries framework and could help inform regulatory decisions under the *Fisheries Act* and *Species at Risk Act*. It would also help guide decisions about future research.
- Methods for studying fish behavior and survival have improved significantly since the studies were undertaken at the Annapolis TiGS. For species and life stages large enough to carry acoustic tags, advances with this technology afford the opportunity to address many of the data gaps. For species and life stages that are too small to carry acoustic tags, research to better understand and improve capture and handling methods, as well as capture efficiency, would lead to a better understanding of the impacts of the Annapolis TiGS.
- The focus of this document is turbine mortality at the Annapolis TiGS and its associated population-level impact. While this focus does address the effects of direct mortality, it does not fully address the impacts of this generating station on fish populations because there is the potential for indirect effects as well. Topics such as changes in habitat quantity and quality, prey availability, or sediment transport that may affect the productivity of clam fisheries in the Annapolis Basin, are not addressed herein. These topics warrant further consideration.

BACKGROUND

The Annapolis River estuary is home to Canada's first tidal hydroelectric generating station, located in Annapolis Royal, Nova Scotia, Canada. Several scientific studies have been undertaken to provide information about fish-related impacts of the Annapolis TiGS, including fishway utilization studies, fish mortality studies and studies of changes in life-history characteristics of fish that use this estuary. The purpose of this advisory process was to provide a summary and evaluation of this information to inform regulatory decisions under the provisions of Canada's *Fisheries Act,* as well as prohibitions under Canada's *Species at Risk Act*. The focus of this process was the mortality of fish associated with passage at the Annapolis TiGS and its direct impacts on the affected population. Indirect effects such as changes in habitat quality and distribution, or prey abundance resulting from the construction and operation of the station or the construction of the causeway, are outside the scope of this review.

Specifically, the following eight terms of reference were addressed in this review:

1. Provide a description of the Annapolis TiGS including its size and capacity, its operation, fish passage facilities, etc., sufficient as background to the literature review.
2. Provide a description of the search effort to identify the relevant literature. Provide a list of publications and identify any that were not included in the review.
3. Describe the fish community in the vicinity of the TiGS. To the extent known, include information about their abundance, life-history, life stages present in the vicinity of the TiGS, their susceptibility to turbine mortality, their resiliency to increased mortality rates, whether the fish are migratory, resident or transient, the months they are present in the vicinity of the TiGS, whether the Annapolis River and/or estuary supports a population of the species, their status, and whether the species directly or indirectly supports aboriginal, commercial or recreational fisheries.
4. Provide a summary and critical review of scientific literature pertaining to fish passage utilization for species identified under TOR 3.
5. Provide a summary and critical review of scientific literature pertaining to fish mortality studies undertaken at the TiGS. Include other evidence of mortality, as appropriate. Include specific mortality rates if available. Describe whether the studies fully characterize the

population-level annual mortality rates (e.g. immediate versus delayed mortality; effects of multiple passes, etc.).

6. Provide a summary of scientific literature pertaining to population-level changes (such as changes to population size and/or structure) that have occurred coincident to the construction and operation of the TiGS. To the extent possible, determine if they are consistent with the mortality rates identified under TOR 5.
7. Provide a summary and critical review of fish diversion studies undertaken at the Annapolis TiGS. Include estimates of their effectiveness for the species identified under TOR 3.
8. For key species identified in ToR 3, provide recommendations for further research to address any information gaps identified in previous TORs.

The products from this advisory process consist of a technical report (Gibson et al. 2019), which includes a critical evaluation of the existing literature and this Science Advisory Report which provides a summary of the technical report and the conclusions of the peer review meeting.

ANALYSIS

TOR 1: Description of the Annapolis Tidal Generating Station.

Facility Description

The Annapolis TiGS is located on the Annapolis River estuary in Annapolis Royal, Nova Scotia. In the early 1960s, a barrage was built between Granville Ferry and Annapolis Royal as a water control structure to allow for the marshland upriver to be used for agriculture without the risk of tidal flooding. This construction transformed the estuary upriver of the causeway from a well-mixed estuary with about a 10 m tidal range (similar to many around the Bay of Fundy) to a highly stratified salt wedge estuary with a tidal range around 0.5 m. The Annapolis TiGS was constructed at the causeway and has been in operation since 1985. The Annapolis TiGS was designed as a prototype to test the STRAFLO™ turbine in anticipation of proposed, large-scale hydroelectric development in the upper Bay of Fundy. Its operation increased the tidal range upriver of the causeway to about 1 - 1.5 m.

The generating station has a low-head propeller turbine that generates only when water is flowing seaward (normal operating head range: 1.4 - 6.8 m). It has a 7.6 m runner diameter and rotates at a rated speed of 50 rpm. Output at a head of 5.5 m was modelled to be 17.8 MW, with a corresponding discharge of 378 m^3/s. The turbine has not been in operation continuously since 1985. Periodically, the turbine has been taken offline for extended periods of time for maintenance or for other reasons (e.g. when a whale was present in the headpond).

Description of Fishways

Two fishways have been constructed to augment fish passage at the Annapolis TiGS. The “old fishway” was built during the original barrage construction in the early 1960s and is essentially a sluice gate, four meters wide, that is kept open throughout the tidal cycle. It is located next to the sluice gates used to fill the headpond about 300 m from the turbine forebay (Figure 1). The “new fishway”, which was constructed at the same time as the generating station, runs between the turbine forebay and the tailrace. It is 3 m wide and is located about 12 m from the turbine intake. It is an unlit square culvert that runs under the highway. Water depth in both fishways varies between 1.5 m and 2.5 m depending on the stage of the tide. Flows through the two fishways vary with the stage of the tide, and have been reported as 42.7 m^3/s and 10.1 m^3/s for the old and new fishways, respectively, for a 0.3 m head.

Depending on the stage of the tide, water may flow in either direction through the fishways providing both landward and seaward fish passage. However, the majority of fish moving landward likely do so via the sluice gates when they are open to fill the headpond.

Operation

The Annapolis TiGS utilizes the water level differential between the headpond and the estuary downstream in order to generate power. This head differential is created by the difference in the tidal range upstream and downstream of the causeway, which is controlled at the causeway. During most tidal cycles, the headpond is filled primarily through the three sluice gates located just south of the generating station (Figure 1), although water also flows landward through the new fishway during filling. The sluice gates are closed when the desired water level in the headpond is reached.

On the ebb tide, once the water level downstream of the turbine drops below the water level in the headpond, water begins to flow seaward initially only through the two fishways. Generation begins once the water level downstream of the causeway drops to about 1.5 m below the headpond level, and continues through the ebb and flood tides until the water level differential is again less than 1.5 m. Water continues to flow seaward through the two fishways until the water level downstream of the causeway reaches the level in the headpond. At this point, the sluice gates are opened to fill the headpond for the next generation cycle. During a typical tidal cycle, the unit generates for about 5.5 hours.

TOR 2: Search Effort

There were two parts to the search undertaken for this review. First, studies that pertain to turbine mortality, fishway utilization, fish diversion or population-level effects at the Annapolis TiGS were identified. Including a previous review, 24 documents were identified in the search for documents directly related to these themes, although the results of these studies are summarized in other documents as well. These were grouped as 12 studies for the purposes of this review (Table 1). The majority of the documents were provided by two researchers who studied fish passage at the Annapolis TiGS and include primary literature, field and technical reports and graduate student theses. Additional searches were undertaken using the Fisheries and Oceans Canada Library and using Google Scholar to help ensure no studies were overlooked. The primary search terms were “Annapolis Royal OR Annapolis River”, with additional searches carried out using “Fish*”, “passage”, “mortality*”, “population*” and “diversion” or “deterrent” to narrow down to specific articles.

The second part of the search effort pertains to TOR 3. After developing a species list from the information obtained in the first component of the search, information regarding the life-history, resiliency, population structure and status of each species was compiled. Sources of information included the primary literature, books, research theses, CSAS documents, NOAA reports, COSEWIC reports and online databases (e.g. FISHBASE). Studies about fish in the Annapolis River and estuary that do not pertain specifically to survival of fish at the Annapolis TiGS were included as appropriate for evaluating the effects of mortality at this site.

Table 1. Fish passage, mortality, population impact, and fish diversion related research at the Annapolis Tidal Generating Station (Y=Yes; N=No). Alosa spp. include Alewife, Blueback Herring and American Shad.

Study Number	Year	Study Description	Field Study	Focus Species	TOR 4 Fishway Utilization	TOR 5 Fish Mortality	TOR 6 Population -level Impacts	TOR 7 Fish Diversion	Publications / Reports
1.	1981 1982	Pre- operational American Shad assessment	Y	American Shad	N	N	Y	N	Melvin et al. 1985
2.	1985 1986	Turbine mortality and fish passage	Y	Herring family, including *Alosa* spp.	Y	Y	N	N	Stokesbury 1985,1986, 1987; Stokesbury and Dadswell 1989; Stokesbury and Dadswell 1991
3.	1985 1986	Observations by SCUBA divers and others	Y	Not species specific	N	Y	N	N	Hogans and Melvin 1985; Hogans 1987; Dadswell and Rulifson 1994
4.	1985 1986	American Shad turbine mortality	Y	American Shad	N	Y	N	N	Hogans and Melvin 1985; Hogans 1987
5.	1988 1989	Fish diversion	Y	*Alosa* spp.	N	N	N	Y	McKinley and Patrick 1988; McKinley and Kowalyk 1989
6.	1989	Juvenile *Alosa* study	Y	*Alosa* spp.	Y	N	N	Y	Ruggles and Stokesbury 1990
7.	1989 1990	Post-operational shad assessment	Y	American Shad	N	N	Y	N	Dadswell and Themelis 1990a, 1990b
8.	1991	Review of fish mortality studies at Annapolis	N	*Alosa* spp.	Y	Y	Y	Y	BEAK Consultants 1991
9.	1993 1994	Juvenile *Alosa* study	Y	*Alosa* spp.	Y	N	N	N	Gibson and Daborn 1993, 1995b; Gibson 1996b

Study Number	Year	Study Description	Field Study	Focus Species	TOR 4 Fishway Utilization	TOR 5 Fish Mortality	TOR 6 Population -level Impacts	TOR 7 Fish Diversion	Publications / Reports
10.	1995 1996	Shad assessment	Y	American Shad	N	N	Y	N	Gibson and Daborn 1995a, Gibson 1996a
11.	1999	Fish diversion and mortality	Y	*Alosa* spp. others	Y	Y	N	Y	Gibson and Myers 2000, 2002a, 2002b
12.	2018	Population-level effects	N	American Shad, Striped Bass, Atlantic Sturgeon	N	N	Y	N	Dadswell et al. 2018

TOR 3: Description of the Fish Community in the Vicinity of the Annapolis TiGS

Fish

The Annapolis River and estuary are home to a variety of marine, diadromous, and freshwater fishes. Forty species were identified during this review as being present in the vicinity of the Annapolis TiGS (Gibson et al. 2019). This list is not all inclusive: other species may be present intermittently or in low abundance, or were missed due to sampling gear selectivity, timing of sampling events, location and/or effort.

A summary of the distribution, fisheries, life-history, biological characteristics and available information relevant to mortality and passage at the Annapolis TiGS is provided in Gibson et al. (2019). This information was used for a qualitative assessment of the expected impact of the Annapolis TiGS on fish populations that was undertaken as part of this review. This assessment was undertaken at the level of a closed population. A population of a specific species is considered closed if intrinsic factors such as growth, reproductive rates, carrying capacity, natural mortality, and mortality caused by human activities are the significant factors determining the population's dynamics; while extrinsic factors such as immigration and emigration are minimal and can be ignored. This definition aligns closely with the goals of assessment, which are to determine whether mortality rates and abundances are within appropriate limits. Under this definition, more than one population of a particular species may be present in the vicinity of an activity or project. Striped Bass are an example of such: historically, individuals from both a native population and from populations native to other rivers were present in the vicinity of the Annapolis TiGS.

Population-level impacts of the Annapolis TiGS were categorized using the definitions set forth in DFO guidance on assessing threats, ecological risk, and ecological impacts for species at risk (DFO 2014). Potential population-level impacts are categorized as “extreme”, “high”, “medium”, “low”, or “unknown” (Table 2) based on the effect that fish passage mortality at the Annapolis TiGS could be expected to have on the size of the population as a whole. Uncertainty in the population-level impact is categorized on a five point scale from “very low” to “very high”, based on the information available about population structure, life-history and turbine mortality rates (Table 3). “Very low” uncertainty corresponds to a well-defined population with strong evidence for the effects of mortality, while “very high” uncertainty corresponds to a species with little to no information on population structure, life-history or turbine mortality rates.

Table 2. Categories for the population-level impact of turbine mortality at the Annapolis Tidal Generating Station. Modified from DFO (2014).

Level of Impact	Definition
Extreme	Severe population decline (e.g. 71-100%) with the potential for extirpation
High	Substantial loss of population (31-70%)
Medium	Moderate loss of population (11-30%)
Low	Little change in population (1-10%)
Unknown	No prior knowledge, literature or data to guide the assessment of threat severity on population

Table 3. Categories for the uncertainty in the population-level impact of turbine mortality at the Annapolis Tidal Generating Station.

Uncertainty	Definition
Very High	Little to no information on population structure, life-history or turbine mortality rates
High Moderate Low	↓ Increasing information quantity, data certainty, and reliability relating to population structure, life-history and turbine mortality rates
Very Low	A well-defined population with strong evidence for the effects of mortality

In addition to the mortality rate for fish passing through the turbine, there are several other factors that contribute to the impact on a population, including: the resiliency of the population to increased mortality rates; the proportion of the population in the vicinity of the turbine; the number of times that individuals move past the causeway; the proportion of the population that use the fishways; the timing of mortality relative to life-history events such as growth, maturation, reproduction and density-dependent processes that regulate population size; and rates of mortality associated with other human activities. The available information about these factors, along with uncertainty in the data for each factor, contributes to the categorization of both the population-level effect and the uncertainty associated with it.

The level of impact and uncertainty for each of the 40 fish species identified in this review is summarized in Figure 2. Further details about the qualitative risk assessment, including the rationales for the assignment of the level of impact and uncertainty for each species, are available in Gibson et al. (2019). Many of the populations that are present around the Annapolis TiGS have a “low” population-level impact because the population has a wide geographic distribution with only a small portion of the population encountering the Annapolis TiGS. For several species, the potential population-level impact is categorized as “low”, but with “high” or “very high” uncertainty. For the majority of the populations with these categorizations, the major source of uncertainty is the population structure and whether a significant portion of the population would be exposed to the turbine.

The results of the impact assessment were used to identify the highest priority species for studying the impacts of turbine mortality. These species are those for which a COSEWIC assessment resulted in a status designation of extirpated, endangered, threatened or special concern; those SARA-listed as extirpated, threatened or endangered; and those species that support commercial, recreational, or aboriginal fisheries for which the expected population-level impact is categorized to be greater than “low”. There are 13 species that meet one of these criteria. Species with a COSEWIC designation are: American Eel, Atlantic Salmon (Southern Upland designatable unit), Atlantic Sturgeon (Maritimes designatable unit), Atlantic Wolffish, White Hake (Atlantic and Northern Gulf of St. Lawrence designatable unit), Lumpfish, Spiny Dogfish (Atlantic designatable unit) and Striped Bass (Bay of Fundy designatable unit). Of these, the Atlantic Wolfish is the only species that is listed under the *Species at Risk Act*; decisions about whether or not to list are pending for other species. Species that support fisheries with an expected impact above “low” are: Alewife, American Shad, Atlantic Menhaden, Blueback Herring and Rainbow Smelt. Species with “high” or “very high” uncertainty are the next highest priorities for research.

Level of Impact	Uncertainty: Very Low	Uncertainty: Low	Uncertainty: Moderate	Uncertainty: High	Uncertainty: Very High
Extreme				• Striped Bass (Annapolis) • Atlantic Salmon	
High				• Atlantic Sturgeon (Annapolis)	
Medium			• American Shad • Alewife • Blueback Herring	• Rainbow Smelt	• Atlantic Menhaden
Low	• Bluefish • Flying Gurnard • Meek's Halfbeak	• Atlantic Mackerel • Atlantic Wolffish • Pollock • Smooth Flounder • Spiny Dogfish • White Perch	• American Eel • American Sand Lance • Atlantic Herring • Atlantic Silverside • Blackspotted Stickleback • Butterfish • Cunner • Fourspine Stickleback • Hake • Longhorn Sculpin • Lumpfish • Sea Lamprey • Sea Raven • Striped Bass (Shubenacadie) • Striped Bass (other) • Threespine Stickleback • Windowpane • Winter Flounder • Wrymouth • Mummichog	• Atlantic Sturgeon (Saint John) • Four-beard Rockling • Ninespine Stickleback • Northern Pipefish • Rock Gunnel	• Atlantic Tomcod

Figure 2. Species matrix for the expected population-level impact and uncertainty for 40 species which encounter the Annapolis TiGS. Because fish from more than one population of the same species may encounter the turbine, Striped Bass is evaluated for three groups: a native Annapolis River population, the population from the Shubenacadie River, and other populations (e.g. US origin or other Canadian-origin), and Atlantic Sturgeon is evaluated for two populations: a possible native population and the population from the Saint John River.

Marine Mammals and Sea Turtles

Two records of whales in the vicinity of the Annapolis TiGS were identified during this review. A Humpback Whale became trapped in the Annapolis River upstream of the Annapolis TiGS in 2004, but it is presumed to have successfully navigated the Annapolis causeway and returned to the Annapolis Basin. The lone whale mortality event at the Annapolis TiGS was attributed to an immature Humpback Whale (possibly a Minke Whale) discovered near the head of tide in Bridgetown in 2007 during the spring thaw. Both occurrences of whales at the Annapolis TiGS appear to be isolated instances, and the population-level impacts are “low” with “low” uncertainty.

Seals are often present at the Annapolis TiGS and appear to move freely between the tailrace and the headpond using the sluice gates. No documented accounts of turbine mortality on seals from the Annapolis TiGS were found during this review. All seals observed were not identified to species. However, the population structure and large population size of the four potential species present in the Bay of Fundy indicate that the seals present at the Annapolis TiGS would represent only a small portion of the population regardless of the species.

No records of the presence of sea turtles near the Annapolis TiGS were found during this review.

TOR 4: Fishway Utilization Studies

As described under TOR 1, fish have three options for moving downstream at the Annapolis TiGS: the old fishway, the new fishway or through the turbine. Upstream movement is almost entirely though the sluice gates when the headpond is being filled. When migrating downstream, the proportion of individuals utilizing each route is an important determinant of the population-level impacts of the station. To date, there have been four studies that provide information about downstream movement (fishway versus turbine usage) for *Alosa* species, three of which have information on other species. These are: the *Alosa* studies in 1985 and 1986, the juvenile *Alosa* study in 1989, the juvenile *Alosa* migration studies in 1993 and 1994, and the fish diversion studies in 1999 (see Table 1).

Studies of fishway utilization have been able to report relative catches of fish from ichthyoplankton nets at the three possible routes through the Annapolis causeway indicating that, with the exception of Atlantic Silverside, the majority of individuals pass downstream through the turbine. The proportions caught at each of the three locations is not directly indicative of the proportion of fish utilizing each route of passage because the nets capture a different proportion of the fish utilizing each route. This capture efficiency has not been well determined in any of the studies.

Proportions of the total catch coming from the fishways versus the tailrace varied among studies, potentially due to differences in the efficiency of the nets being used or differences among years. For example, during monitoring in 1985 and 1986, 2% of the catch of young-of-the-year America Shad, Alewife and Blueback Herring came from the two fishways, and 98% of the catch of these species came from the tailrace. However, when monitoring with a modified net in 1993, 28% of the catch of these species were caught in the two fishways and 72% in the tailrace, a substantial difference. These studies also show that fishway usage is highly variable among species.

With respect to estimating the proportion of fish moving downstream through the fishways, the studies provide coarse information that is best interpreted qualitatively for at least two reasons. First, capture efficiency would be expected to vary among species and locations, and results from one species should not be compared with other species for this reason. Second, the proportions of fish captured in the tailrace and two fishways reported in some of these studies are not corrected for the number of generation cycles that were sampled at each location. Without further information about capture efficiencies and coverage, the actual proportion of individuals selecting each route remains unclear. However, given the large cross-sectional size of the tailrace relative to that of the fishways, these studies provide evidence that the large majority of individuals move downstream through the turbine.

The fishway utilization studies do provide some rough information about the numbers of fish passing through the turbine. During the 1999 study, the capture efficiency of two nets fished in the tailrace was estimated to be one out of every 335 fish that pass through the turbine. During the 1994 study, just over 3,600 fish were captured in the tailrace using the same fishing methods. These results indicate that over 1.2 million fish would have passed through the turbine during the 70 tidal cycles that were monitored in 1994 between the end of July and mid-November. Similarly, in 1999, roughly 1 million fish would be expected to have passed through the turbine on the 48 tidal cycles monitored between early September and late October (roughly half of the tidal cycles in the study period). These estimates do not include larger fish that were not susceptible to capture in the one-meter-diameter nets.

TOR 5: Fish Turbine Mortality Studies at the Annapolis TiGS

Turbine mortality studies can be divided into two groups: those that use fish experimentally released into the turbine intake and those that use naturally entrained fish captured in nets in the turbine tailrace. Turbine mortality studies can be further divided into those that estimate mortality rates immediately after fish pass through the turbine (short-term or acute), and those that estimate rates that quantify mortality occurring over a longer period (delayed mortality), the latter of which is by far more relevant for determining the population-level impacts of the mortality but much harder to estimate. There have been three studies at the Annapolis TiGS that have reported turbine mortality rate (the probability that a fish passing through the turbine dies as a result of passage) estimates: the 1985-86 adult American Shad mortality rate study, the 1985-86 young-of-the-year clupeid study, and the 1999 fish diversion and mortality study. The first of these studies used experimentally released fish, while the latter two studies used naturally entrained fish. In addition, there is documentation of mortality of fish at the Annapolis TiGS from diver and shoreline observations. Overall, these studies provide evidence that there is mortality associated with turbine passage occurring at the Annapolis TiGS. However, for the majority of species the rates of mortality associated with turbine passage, particularly delayed mortality, are not well quantified.

When interpreting the turbine mortality rate estimates, it is important to remember that the turbine mortality rate alone does not determine the impact on the population. First, if some portion of the population moves past the causeway via the fishways, overall survival will be higher than what is implied by the turbine mortality rate. Second, if fish move back and forth past the causeway more than one time, they may pass through the turbine more than one time. In this case, the overall survival will be lower than that implied by the mortality rate for a single pass through the turbine. Additionally, many of the biases in turbine mortality rate studies lead to single-pass estimates that are biased high (Gibson et al. 2019).

Observational Records

Observations of dead fish below the Annapolis TiGS have been recorded intermittently since the construction of the generating station. During the 1985 and 1986 fish mortality studies, dead fish were collected or observed on the bottom of the estuary by SCUBA divers or observed along the shoreline or on the water surface. In total, 4,428 individuals from 11 species were observed dead downstream of the turbine during 1985-1986, about 90% of which were Atlantic Herring and Blueback Herring. These records also include observations of larger fish, including Atlantic Mackerel, flounder spp., American Shad, Striped Bass, and Atlantic Sturgeon. There have been other observations of fish mortality since that time (e.g. 21 records of Atlantic Sturgeon from 1985 to 2017). Overall, these records provide credible evidence of fish mortality occurring at the Annapolis TiGS.

Turbine Mortality Rate Studies

The mortality of adult American Shad passing through the turbine was studied during 1985 and 1986 using experimentally-released, sonically-tagged fish. In 1985, 24 fish were tagged using sonic transmitters inserted into their esophagus and released in four batches during the study period. High handling and tagging mortality led a previous reviewer to question the resulting estimate. The same general study design was used during 1986, but methods were improved resulting in lower mortality from handling and tagging. After accounting for control mortality, the mean turbine mortality rate from this study was calculated to be 21.3% (90% CI: ±15.2%) for a single pass downstream through the turbine. A previous review and the lead author of the 1985 and 1986 studies considered the 1986 estimate to be better due to reduced mortality as a result of better handling techniques.

Other studies of turbine mortality at the Annapolis TiGS used one-meter-diameter ichthyoplankton nets to capture naturally entrained clupeids (members of the herring family) that had passed through the turbine. In the initial studies during 1985 and 1986, nets were fished for two to five hours. The majority of fish captured were dead when removed from the net. Fish were autopsied to determine the cause of death, although it is unclear whether the methods clearly distinguish between mortality caused by the net and that caused by turbine passage. The effect of the net was determined by capturing fish upstream and placing them in the tailrace nets for either 30 or 60 minutes, a time period that is short relative to the length of time that a fish would be expected to be in the nets. This would be expected to lead to an underestimate of the mortality associated with capture in the net. The resulting turbine mortality rate estimate is likely biased high for these reasons.

Building on the previous work, the purpose of the 1999 study was to trial a new method in which the nets were deployed for varying lengths of time and logistic regression methods were used to estimate the survival of fish that had not spent time in the net. The study demonstrated the method using data for naturally-entrained fish at the Annapolis TiGS that were captured in the tailrace using ichthyoplankton nets. Twelve species were captured in sufficient numbers to estimate acute turbine mortality rates. These ranged from 0.0% for Sea Lamprey to 23.4% (95% confidence interval (C.I.): 6.1 to 58.8%) for young-of-the-year American Shad (Table 4). Large confidence intervals are associated with some of the estimates. Two aspects of turbine mortality studies that were not addressed in the 1999 study are handling mortality caused by sources other than the length of time in the net and delayed mortality. If significant, the first of these issues would lead to estimates that are biased high. If fish killed by turbine passage do not die shortly after turbine passage, then acute turbine mortality rates would not sufficiently quantify turbine mortality.

The estimates of the turbine mortality rates from the 1999 study for 12 species and from the 1986 study for adult American Shad are the best available at the Annapolis TiGS. However, neither study fully accounts for the capture and handling processes, and neither study fully addresses delayed mortality after turbine passage.

The turbine mortality rate estimates from all studies are for a single pass through the turbine. Some species, especially species that are resident in the vicinity of turbine, have the potential to make multiple passes through the turbine throughout the course of the year. In this situation, the total mortality rate resulting from turbine passage is a function of the turbine mortality rate and the expected number of passes through the turbine. The number of passes that fish would be expected to make through the turbine has not been studied for any species. Additionally, with the exception of the adult American Shad, turbine mortality rate studies are limited to species amenable to capture in one-meter-diameter nets. As such, no information is available for larger fish species and older life stages at the Annapolis TiGS. Turbine mortality rates are expected to be variable among species, as evidenced by the results of 1999 study. Delayed mortality has not been sufficiently addressed in the studies to date.

Table 4. Estimates of acute mortality for 12 species of fish captured using ichthyoplankton nets at the Annapolis Tidal Generating Station (adapted from Gibson and Myers 2002a). YOY = young-of-the-year; C.I. = confidence interval.

	Mortality (%)		
Species	mean	95% C.I. lower limit	95% C.I. upper limit
YOY American Shad	23.4	6.1	58.8
YOY Blueback Herring	8.1	3.5	17.2
YOY Alewife	7.7	1.5	31.4
YOY Atlantic Herring	15.7	10.8	22.1
Sea Lamprey	0.0	n/a	n/a
Blackspotted Stickleback	<0.1	<0.1	5.6
Atlantic Silverside	2.2	1.1	4.1
Northern Pipefish	2.2	0.7	6.4
Butterfish	8.7	1.7	34.5
Winter Flounder	5.8	0.8	31.2
Windowpane	8.8	<0.1	59.4
Hake (spp.)	8.7	0.3	20.9

TOR 6: Studies Evaluating Population-Level Impacts of Fish Mortality at the Annapolis TiGS

Population-level effects of the Annapolis TiGS have been monitored for one species only, American Shad, but impacts have been inferred for Striped Bass based on recreational fishing records, and for Atlantic Sturgeon based on observations of dead fish.

American Shad

Studies of the American Shad population in the Annapolis River were conducted in 1981 and 1982 to establish a pre-operational baseline of the population characteristics before the Annapolis TiGS was constructed. Post-operational studies were undertaken in 1989 and 1990, about one generation (c. six years) after the turbine came online, and in 1995 and 1996, roughly two generations after the turbine came online. All three studies (1981/82, 1989/90, and 1995/96) recorded, mostly by sex, the mean and maximum observed length, the mean and maximum observed weight, the mean and maximum observed age, the percentage of repeat spawners, the mean age at maturity, vonBertalanffy growth rate parameters, and the total mortality rate.

Comparison of the characteristics of the American Shad spawning run before and after the turbine came on-line indicate that there has been a decline in the mean size, mean age, maximum observed age, age-at-maturity, and percent of repeat spawners, and an overall increase in the total mortality rate.

Comparisons of these assessments must be undertaken with caution for several reasons, including: differences in sampling gear, variable timing and locations of sampling, potential for recruitment variability to markedly influence biological characteristics, difficulties estimating total mortality rates from data collected in a single year and lack of information about the effects of other factors (e.g. fisheries) that would affect the population's biological characteristics. Despite these limitations, the studies do indicate that there have been changes to the population structure. Most notable is the decrease in the maximum age observed for both male and female American Shad between the pre- and post-operational assessments. The sampling in 1995 and 1996 occurred throughout the river and, if older American Shad were present in the population those years, they likely would have been observed. This change, which is indicative of higher mortality rates for adult fish, lends credibility to the decrease in size and mean age observed in the post-operational assessments.

While the changes in the total mortality rates from these studies are not inconsistent with the 1986 turbine mortality rate estimate for adult American Shad (described in ToR 5), there are caveats associated with interpreting these data. First, the changes in total mortality rates and the turbine mortality rates are not directly comparable. The turbine mortality estimate may not be representative of the overall survival of fish passing the causeway because adult American Shad have been observed using the new fishway, and conversely, the potential exists for a fish to pass through the turbine multiple times. Second, the estimated change in the total mortality rate is greater than what would be expected from the 1986 turbine mortality rate alone. Consequently, neither the change in the total mortality rates nor the passage survival rates are well known. This said, an increase in mortality rates for adult American Shad associated with passage at the Annapolis TiGS would lead to changes in the biological characteristics of the population in the direction observed in these studies.

Striped Bass

Information for assessing the population-level effects of the Annapolis TiGS on the Annapolis River Striped Bass population is limited to information on length, weight, and catch and effort data from creel surveys, questionnaires, fishing contests, and private angling records; data which may not be representative of the native Annapolis River Striped Bass population. These records indicate a decrease in the proportion of large fish in recreational landings in the Annapolis River estuary, together with decreases in the overall CPUE and average size of fish. These changes have been attributed to size-selective turbine mortality.

There are two factors that need to be considered when evaluating the population-level impacts of the Annapolis TiGS on Striped Bass. First, some of the changes to the Annapolis River Striped Bass population occurred before the construction of the turbine. Second, the assemblage of Striped Bass in the Annapolis Basin consists of Striped Bass from more than one population, although the actual composition is not known and likely has varied through time.

Prior to the construction of the Annapolis TiGS, there was concern with the egg survival of Striped Bass in the Annapolis River. While eggs were obtained from the Annapolis River in several years between 1976 and 1994, the last larvae captured were in 1976. Seine surveys in 11 years between 1976 and 2015 have not captured any young-of-the-year Striped Bass. Together, these results provide evidence that Striped Bass have not been successfully reproducing in the Annapolis River since at least the mid-1970s. Creel surveys in 1976 indicated an increase in the average size of fish, which would be consistent with reproductive failure (i.e. reproductive failure alone would be expected to lead to increase in the size of fish until the last fish are gone). COSEWIC (2012) concluded that the Annapolis River Striped Bass population is extirpated.

In contrast, Striped Bass (age 2 and older) have continued to be captured in the Annapolis estuary from the 1980s to present. The source of these fish is not known: they could be from reproduction in the Annapolis River, be transients from other populations, or be some combination thereof. Both genetic and tagging studies have shown that Striped Bass undergo coastal migrations and forage in estuaries other than those at the mouths of their natal rivers. Striped bass tagged elsewhere, including USA rivers, have been captured in the Annapolis River estuary, and Striped Bass tagged in the Annapolis River have been recaptured in other areas. In both cases, the actual origin of the fish is not known and the number of recaptured fish is small. The relative abundance of natal and non-natal fish in the Annapolis River estuary would be expected to vary depending on many factors including the abundance decline of the Annapolis River population. Based on this information, the Annapolis TiGS is not the only factor that would contribute to the documented changes to the size distribution of Striped Bass in the Annapolis River. The present composition of the Striped Bass assemblage in the Annapolis River is not known.

This said, there is evidence that the Annapolis TiGS kills Striped Bass. Turbine mortality would be expected to hasten the decline in abundance, and also has the potential to limit population growth if the river is recolonized. However, the paucity of information about the rates of mortality of Striped Bass moving past the causeway precludes an evaluation of the population-level effect of the Annapolis TiGS on the Annapolis River Striped Bass population.

Atlantic Sturgeon

The major question regarding the impacts of the Annapolis TiGS on Atlantic Sturgeon is whether or not there is a population native to the Annapolis River. A 1922 publication states: “They [Atlantic Sturgeon] are known also in the Annapolis river, which they are said to ascend as far as Middleton.” There is a paucity of information about this species in this river and, similar to Striped Bass, sturgeon encountering the Annapolis TiGS may be part of a native population or else may be transient fish from other populations. Atlantic Sturgeon are known to have a large home range and their foraging habitat includes foraging habitat in non-native rivers.

As reported in a 2018 publication, information about the effects of the TiGS on Atlantic Sturgeon in the Annapolis River is comprised of 21 records of dead fish found downstream of the turbine from 1985 to 2017, many with injuries consistent with turbine mortality. More fish have subsequently been found. Maturity was determined for 11 of the 21 mortalities and consisted of four ripe females, three spent females, two ripening males, one spent male and one immature animal. This information has been interpreted as evidence that there is currently a population of Atlantic Sturgeon native to the Annapolis River. However, the origin of these sturgeon has not been determined. Given the small sample size (11 fish for which maturity was determined over 32 years), these data are weak evidence of the presence of a population native to the Annapolis River. Young-of-the-year sturgeon (indicative of local reproduction) have not been captured in the Annapolis River, although there have not been any surveys designed specifically for this species. The presence of a native population at this time is not definitively known.

A population-level impact cannot be determined from this information alone. If the sturgeon are from the Saint John River population, then the effect on that population is likely quite low.

However, if there is a population native to the Annapolis River, the effects of turbine mortality on a native population would be expected to be high.

TOR 7: Fish Diversion Studies at the Annapolis TiGS

Fish diversion systems can be separated into two categories; physical and behavioral. Physical barriers have been considered impractical at the Annapolis TiGS due to its large size, debris, and the small size of most fish.

Studies at the Annapolis TiGS during 1988, 1989 and 1999 examined the effectiveness of four fish diversion technologies for reducing the passage of fish through the turbine: a fish drone and filtered mercury vapour lights to attract fish to the fishway; and fish hammers and ultrasound to deter them away from the turbine intake. The 1988 study found that a fish drone and filtered mercury vapour lights were not effective in attracting fish towards the fishways. The results from the 1989 study indicated that fish hammers could be used to deter fish away from the turbine intake. The study was not species-specific; Alewife and American Shad were the most abundant species captured during sampling. Whether fish deterred away from the turbine then used the fishways was not specifically evaluated during these studies. The results of the 1999 studies showed that the use of an ultrasound fish diversion system at the Annapolis TiGS showed promise for reducing turbine passage of young-of-the-year American Shad, Alewife and Blueback Herring, but not for other species. The effectiveness of a behavioral guidance system depends on the species, time of year, the time of day, the age of the fish, the flow field, environmental conditions, the “motivational state” of the fish, and, as shown in the 1999 study, the abundance of fish. These factors all need to be considered when developing and testing behavioral guidance systems.

TOR 8: Research Recommendations

Fisheries and Oceans Canada has developed a Sustainable Fisheries Framework that provides the basis for ensuring that Canadian fisheries support conservation and sustainable use of resources. The primary components of the precautionary approach framework are reference points and stock status zones (healthy, cautious and critical) intended to inform decision-making. For each stock, a removal reference rate is defined relative to the stock status zones as the maximum acceptable removal rate from all types of fishing and other human activities. For species found in the vicinity of the Annapolis TiGS, identification of reference mortality rates associated with passage at the Annapolis TiGS would ensure that mortality rates are consistent with DFO’s Sustainable Fisheries Framework and could help inform regulatory decisions under the *Fisheries Act* and *Species at Risk Act*. It would also help guide decisions about future research.

More generally, information about the fish community in the vicinity of the Annapolis TiGS is dated. Most of the data collected about the fish community and turbine mortality were collected in the 1980s and 1990s, with the most recent field study occurring in 1999. Population abundances and species assemblages may be different today than they were when these studies were conducted. Additionally, most of the information about the fish community was collected during the late summer and fall, with little to no information about the community during winter and spring. Updating this information is best done concurrently while addressing other research questions.

With respect to evaluating population-level impacts for fish at the Annapolis TiGS, the state of knowledge for the highest priority species identified under TOR 3 is provided in Table 5. Depending on what is considered an acceptable mortality rate, addressing one or more of the information gaps might be sufficient to determine whether mortality rates are within acceptable limits. For example, if the proportion of a population encountering the Annapolis TiGS is less than the acceptable mortality rate then further research would not be required to determine that the mortality occurring is within the acceptable limit.

There have been significant improvements in technology and methods since most of the research was done at the Annapolis TiGS, most notably acoustic tracking technology. Fish passage usage, immediate and delayed turbine mortality rates, residency times and the number of times that fish move past the causeway can now be evaluated using acoustic tracking equipment. These methods are now well-developed for larger-bodied, robust fish. Tracking technologies are not yet developed for smaller-bodied fish (e.g. fish less than 10 g). As such, for these species, capture with nets may be the most appropriate method, with emphasis on research to better understand and improve capture and handling methods, as well as capture efficiency.

For populations for which the population-level impact is categorized as low, but with high or very high uncertainty (TOR 3), the major source of uncertainty is the population structure and whether a significant portion of the population would be exposed to the turbine. For these species, further research about population units and utilization of the Annapolis River estuary could be prioritized over research about survival passing through the turbine.

There are three species for which the level of impact was deemed to be high or extreme, but with high uncertainty. These are Annapolis River populations of Striped Bass, Atlantic Salmon, and Atlantic Sturgeon. For Atlantic Salmon, the key source of uncertainty is survival of smolts and adults migrating past the turbine. These are also unknown for Striped Bass and Atlantic Sturgeon. For Striped Bass, a key source of uncertainty is the status of the Annapolis River population and whether the river could sustain a production of Striped Bass under current conditions. For Atlantic Sturgeon, the presence and status of an Annapolis River population is a key source of uncertainty.

Research with respect to fish diversion and guidance systems at the Annapolis TiGS might best follow after sufficient information is obtained about the impacts of the station on specific species and whether they are within acceptable limits.

Table 5. Information available for assessing the population-level impacts of the Annapolis TiGS (Y = sufficient information, N = information gap). YOY = young-of-the-year

Species	Population definition	Life-history / resiliency	Proportion of the population that would encounter the turbine	Timing of turbine mortality relative to life-history events	Rate of fish passage usage and survival during passage	Acute turbine mortality rates	Delayed turbine mortality rates	Expected number of passes through the turbine	Rates of other human-induced mortality	Reference level defining an acceptable mortality rate
Alewife	Y	Y	Y	Y	N	Y (YOY only)	N	N	Y	N
American Eel	N	N	N	Y	N	N	N	N	N	N
American Shad	Y	Y	Y	Y	N	Y	N	N	N	N
Atlantic Menhaden	N	N	N	N	N	N	N	N	Y	N
Atlantic Salmon	Y	Y	Y	Y	N	Y	N	N	Y	N
Atlantic Sturgeon	N	Y	N[1]	N	N	Y	N	N	Y	N
White Hake	Y	Y	Y	N	N	N	N	N	N	N
Lumpfish	Y	Y	Y	N	N	N	N	N	N	N
Rainbow Smelt	Y	Y	N	N	N	N	N	N	N	N
Spiny Dogfish	Y	Y	Y	N	N	N	N	N	N	N
Blueback Herring	Y	Y	Y	Y	N	Y (YOY only)	N	N	Y	N
Atlantic Wolffish	Y	Y	N	N	N	N	N	N	N	N
Striped Bass	Y (more than one population)	Y	Y for the Annapolis; N for others	Y	N	N	N	N	N	N

[1]If there is a population natal to the Annapolis River, the proportion would be one for that population. For other populations, the proportion is unknown.

Sources of Uncertainty

With respect to understanding the impacts of the Annapolis TiGS, there are many information gaps pertaining to fishway utilization, turbine mortality rates, and fish behavior in the vicinity of the TiGS that preclude definitive statements about its impacts (Table 5). These are described throughout the document. Additionally, the information about the fish community at the Annapolis TiGS is dated. Species composition and relative abundance may have changed since the last field study was conducted in 1999. As such, the information presented on this document reflects the current state of knowledge, which may not be equivalent to the current state of the Annapolis River system. No studies occurred during winter and few in spring. Species expected to be most prevalent during these seasons are not well represented in the available studies.

With respect to the impact analysis provided under TOR 3, impacts were evaluated at the level of a closed population. This is appropriate in the context of an objective of maintaining the overall productivity of these fish stocks. However, the results would be expected to be different if a different objective was used. For example, if maintaining abundance locally to support a recreational fishery was the objective, then a high level of turbine mortality would result in a high level of impact, even if only a small portion of the population encountered the turbine. Similarly, if the management objective is to maintain a trophy fishery, a decline in the local population of older and larger individuals would be categorized as a high impact despite a potentially low impact to the population as a whole.

The focus of this document is turbine mortality at the Annapolis TiGS and its associated population-level impact. While this focus does address the effects of direct mortality, it does not fully address the impacts of this generating station on fish populations because there is the potential for indirect effects as well. Topics such as changes in habitat quantity and quality, prey availability, and sediment transport that may affect the productivity of clam fisheries in the Annapolis Basin, are not addressed herein. These topics warrant further consideration.

CONCLUSIONS AND ADVICE

Studies that pertain to turbine mortality, fishway utilization, fish diversion or population-level effects at the Annapolis TiGS were identified during this review. In total, 24 documents (including a previous review) were identified that are directly related to these themes. These were grouped as 12 studies for the purposes of this review. Together, they describe a diverse fish community consisting of at least 40 species. Research is dated: the most recent field study was completed in 1999. During the mid-1990s, when much of the research was conducted, the abundance of many species was high and the number of fish migrating past the Annapolis TiGS annually at that time is thought to be in the low millions.

There are three routes of passage for fish moving downstream at the Annapolis TiGS: the new fishway, the old fishway and through the turbine tube. Studies of fishway utilization are mostly based on relative catches of fish from ichthyoplankton nets at the three possible routes through the Annapolis causeway, which do not fully quantify the proportion of the fish using each route. The studies do indicate that, with the exception of Atlantic Silverside, the majority of fish pass downstream through the turbine.

There is evidence that mortality of fish occurs at the Annapolis TiGS. This evidence includes: anecdotal reports of dead fish (with injuries consistent with turbine passage) in the vicinity of the Annapolis TiGS, observations of dead fish downstream of the turbine, and in-situ research about survival of fish passing through the turbine.

The Annapolis River American Shad population is the only population for which a comparison of their biological characteristics before and after Annapolis TiGS became operational is available. The results indicate changes in the biological characteristics of this population that are not inconsistent with the turbine mortality rate estimate for adult American Shad. However, the changes cannot be wholly attributed to the turbine without information about fishway usage, the expected number of passes through the turbine each year, and knowledge of other changes that would affect their survival that may have occurred during the 15 years over which these assessments occurred.

The reported decrease in the average size of Striped Bass caught in the recreational fishery in the Annapolis River is not definitive evidence of a population-level change wholly attributable to the turbine. Directed surveys have demonstrated a lack of successful spawning (absence of young-of-the-year bass) in this river and use of habitat in non-natal estuaries has been demonstrated for Striped Bass. As such, the extent to which the fishery data are representative of the Annapolis River Striped Bass population is not known. The present composition of the Striped Bass assemblage in the Annapolis River estuary is not known. This and the paucity of information about the rates of mortality of Striped Bass moving past the causeway precludes an evaluation of the population-level effect of the Annapolis TiGS on the Annapolis River Striped Bass population.

There is weak evidence that there may presently be a population of Atlantic Sturgeon native to the Annapolis River, but its status is not definitively known.

Fish diversion systems, intended to deter fish from passing through the turbine, have been tested at the Annapolis TiGS. The use of ultrasound has shown promise for young-of-the-year *Alosa.* Whether a behavioral guidance system can be developed that would be effective for all species at the Annapolis TiGS is not known but is unlikely.

Many of the data gaps with respect to the survival of fish at the Annapolis TiGS can now be addressed as a result of recent technological advances in fish tracking. Development of reference mortality rates associated with passage at the Annapolis TiGS would help ensure that mortality rates are consistent with DFO's sustainable fisheries framework and could help inform regulatory decisions under the *Fisheries Act* and *Species at Risk Act*. It would also help guide decisions about future research.

LIST OF MEETING PARTICIPANTS

Name	Affiliation
Arany, Jillian	Confederacy of Mainland Mi'kmaq
Avery, Trevor	Acadia University
Bradford, Rod	DFO Science - Maritimes Region
Broome, Jeremy	DFO Science - Maritimes Region
Cliche, Levi	Clean Annapolis River Project
Comeau, Peter	DFO Science - Maritimes Region
Daborn, Graham	Acadia University
Enders, Eva	DFO Science - Central and Arctic Region
Ford, Jennifer	DFO Science - Maritimes Region
Fulton, Samantha	DFO Science - Maritimes Region
Gibson, Jamie	DFO Science - Maritimes Region

Name	Affiliation
Harper, Danni	Acadia University
Holland, Heather	NS Power Inc
Hominick, Craig	DFO Fisheries Protection Program - Maritimes Region
Humphrey, Donald	DFO Species at Risk Management - Maritimes Region
Levy, Alex	DFO Science - Maritimes Region
Marshall, Charlie	Atlantic Policy Congress of First Nation Chiefs Secretariat
Mitchell, Vanessa	Maritime Aboriginal Peoples Council
Porter, Darren	Minas Basin Brush Weirs
Raab, Dustin	DFO Science - Maritimes Region
Redden, Anna	Acadia Centre for Estuarine Research
Robichaud-LeBlanc, Kim	DFO Species at Risk Management - Maritimes Region
Stevens, Greg	DFO Resource Management - Maritimes Region
Stokesbury, Mike	Acadia University
Themelis, Daphne	DFO Science - Maritimes Region
Walmsley, Jay	NS Power Inc
Worcester, Tana	DFO Science - Maritimes Region

SOURCES OF INFORMATION

This Science Advisory Report is from the January 9-10 and March 6, 2019 Review of Existing Scientific Literature to Determine the Level of Fish Mortality and Potential Impacts on Fish Populations as a result of the Operation of the Annapolis Tidal Power Facility. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada Science Advisory Schedule as they become available.

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