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DETERMINATION OF THE SIGNIFICANCE OF PROPONENT-REPORTED ANNUAL MORTALITY AT THE POINT LEPREAU GENERATING STATION

Context

New Brunswick Electric Power Corporation (NB Power) conducted impingement and entrainment monitoring at the Point Lepreau Nuclear Generating Station (PLNGS), as a requirement for a license renewal process with the Canadian Nuclear Safety Commission (CNSC). A self-assessment report (EcoMetrix 2017) prepared by NB Power provided analysis and interpretation of the results of impingement and entrainment sampling. It was reported that the current operation of the station may be causing residual, serious harm to fish that are part of, or support, a commercial, recreational, or Aboriginal (CRA) fishery. Consequently, NB Power was required to apply for authorization under paragraph 35(2)(b) of the *Fisheries Act* in order to be compliant with the *Act*.

Since the request for an authorization under paragraph 35(2)(b) of the *Fisheries Act* for the PLNGS was received prior to the coming in force of the current *Fisheries Act* (2019) and met the transitional provisions, the impacts of these studies were evaluated under the 2012 *Fisheries Act*, which prohibited works, undertakings and activities that would result in serious harm to fish that were part of or that supported a CRA fishery (paragraph 35(1)). In 2019, the *Fisheries Act* was modernized to restore the protection against the death of fish, other than by fishing (paragraph 34.4(1)) and the harmful alteration, disruption or destruction of fish habitat (paragraph 35.2) to all fish and fish habitat.

Fisheries and Oceans Canada (DFO), Fish and Fish Habitat Protection Program (FFHPP) requested advice from DFO Science to determine if the serious harm to fish reported by NB Power could be offset or if it would prevent DFO from attaining fisheries management objectives. This advice would inform the decision-making process for authorization. The authorization has since been issued, based on informal advice; however, FFHPP requested the advice be published to ensure the advice that supported the authorization is formally documented, and to support the decision-making process related to offsetting requirements if NB Power constructs a second reactor or modifies its water intake requirements.

The objective of this peer review process is to review the self-assessment report submitted by NB Power on impingement and entrainment monitoring and reported mortality at the PLNGS, and to evaluate the methods employed to estimate annual reported losses. The field methods used in the self-assessment do not address other sources of mortality, such as impingement on the cooling water system's trash racks or marine mammal (seals) mortality. The discharge of the cooling water or the potential impacts of the thermal plume are not subject to an authorization under paragraph 35(2)(b) of the *Fisheries Act*, as these may be considered a deleterious substance under the provisions of paragraph 36(3) of the *Fisheries Act,* which is administered by Environment and Climate Change Canada (ECCC). A Thermal Plume Assessment was initiated in support of the Environmental Risk Assessment in May 2018. The final version of the report regarding this study was submitted to the CNSC in June of 2020. The following seven terms of reference (TOR) are addressed in this review:

With respect to the entrainment/impingement study provided by the proponent:

1. Are the field methods and analytical methods used to evaluate impingement and entrainment consistent with best practices?
2. Is the species list representative of the species targeted by commercial, recreational, and Aboriginal (CRA) fisheries in the area?
3. Are the population units and life history values used in the analysis applicable to the species?

With respect to the ‘significance’ of reported annual mortality:

4. Will the reported annual mortality have an effect on the localized population levels?
5. Will the reported annual mortality result in losses in future productivity (i.e., the calculations in the report do not consider subsequent offspring losses or cumulative impacts)?
6. The report gives mortality rates, can this be extrapolated to indicate an impact on CRA fisheries?

In addition, FFHPP had requested science advice on the following question:

7. What are the possible mitigation and offsetting methods that could be implemented to reduce the impacts associated with the operations of the PLNGS?

This Science Response Report results from the regional peer review of March 21, 2023, on the Review of Impingement and Entrainment Monitoring and Reported Mortality at the Point Lepreau Nuclear Generating Station.

Background

The Point Lepreau Nuclear Generating Station (PLNGS, owned and operated by New Brunswick Electric Power Corporation (NB Power), is a CANada Deuterium Uranium (CANDU-6) nuclear generating station located near Saint John, New Brunswick, on the shore of the Bay of Fundy (BoF). It began commercial operation in 1983. Sampling was undertaken at the PLNGS to determine which species are susceptible to impingement (being trapped against screens) between October 2013 and August 2014 and to entrainment (being drawn into and through the cooling system) between October 2014 and October 2015. Based on these results, total numbers of each species that were impinged or entrained in the system were estimated. Subsequently, models were used to estimate losses of age-1 equivalents, foregone production, and potential losses to fisheries.

Description of Cooling Water System at the PLNGS

Description of the cooling water (CW) system at the PLNGS was summarized from information from multiple sources, notably: the self-assessment report (EcoMetrix 2017), the impingement study report (Arcadis 2016a), the entrainment report (Arcadis 2016b), and the CW system design manual (Albery Pullerits Dickson and Associates 1982). The CW system takes in seawater approximately 700 m offshore of the PLNGS at Point Lepreau, N.B., near the mouth of the BoF. The structure is located on the seafloor at 16 m depth (mean low tide), is 6 m in height, and is placed on a 2.5 m riser. The CW intake is designed to minimize the intake of marine organisms through the inclusion of a velocity cap that reduces the velocity of incoming water, while the riser prevents lobsters and other benthic species from crawling or swimming into the intake. Coarse screens could be added to the velocity cap to prevent marine mammals or schools of larger fish from entering the intake; however, further studies (e.g., engineering and cost-benefit analysis) would be required to maintain the safety of the nuclear reactor. The intake velocity is approximately 0.27 m/s, which is slower than the prolonged swimming speed of large fish species such as Atlantic Herring; however, small invertebrates, fish larvae, and fish eggs are drawn into the cooling system, which may result in a mortality event. Seawater taken in by the CW system travels underground to the forebay, an open-air channel, that leads to the pump house. At the entrance of the pump house are a set of louvered trash racks that block large debris from entering the pump house. The forebay, is set at a 17.5° incident angle to the trash racks, such that the dominant water flow approaches at that same angle. The trash racks are followed by a set of eight fine mesh screens to block smaller debris and fish from entering the pump house. The fine mesh screens, dubbed “travelling screens” by the authors, can be rotated vertically to be washed by an automated screen washing system. The automated screen washing system is triggered individually on each of the eight travelling screens whenever built-up debris causes a pressure differential to surpass a set threshold value. Wash water is then recirculated back into the forebay. After passing through the screens, water is either pumped to the generating facility for cooling or pumped to the recirculating water system. Used seawater is then discharged 900 m offshore on the opposite side of the Point Lepreau peninsula to the intake.

Analysis and Response

Are the Field Methods Used to Evaluate Impingement and Entrainment Consistent with Best Practice?

NB Power contracted Arcadis to undertake two studies exploring impingement and entrainment of organisms in the cooling water system of the PLNGS. Specific details of the field methods can be found in the separate impingement study (Arcadis 2016a) and entrainment study (Arcadis 2016b) reports.

Impingement

Impingement Field Methods

All impingement field methods described herein are based on information reported in Ecometrix (2017) and the associated Arcadis reports (Arcadis 2016a,b). There are aspects of the methodologies that would benefit from a more detailed description to enable a thorough evaluation of best practices. All impingement samples were collected from the wash-water resulting from washing impinged debris, either automatically or manually, from the travelling screens located between the fixed louvres/trash rack at exit of the forebay into the pump house of the CW system. The mesh size of the travelling screen is reported by EcoMetrix (2017) as 9.5 mm and by Arcadis (2016a) as 12.7 mm. Under normal operation, the travelling screens would be intermittently cleaned by an automated screen washing system. The automated travelling screen washing system is triggered individually, for each of the eight travelling screens, when the build-up of debris causes the pressure differential across the screen to surpass a set threshold. Once activated, the travelling screen is lifted and washed, with the wash-water collecting in the sluiceway. This description is based on the reports provided.

Two sampling designs were used during the impingement study. The first sampling design, used from July 25, 2013 to October 25, 2013, provided 37 samples. It consisted of two consecutive 12-hour sampling periods and relied on the automated screen washing system to wash the screens during the sampling period. Delineation between the two 12-hour periods was done to address diel variability. This sampling design was discontinued due to the automated screen washings not aligning with the 24-hour sample period, causing low collection numbers.

Sampling using the second, modified sampling design ran from October 28, 2013 to August 28, 2014, for a total of 84 samples. A planned outage occurred from May 3, 2014 to July 2, 2014, and data collected during this period were omitted from the study. For the modified sampling, the automated screen washing system was turned off and the screens were manually lifted and washed. Each screen was washed every seven days, with screens 1 to 4 being washed on Tuesdays and screens 5 to 8 being washed on Thursdays. All screens were not washed at the same time due to site access and safety restrictions.

For both sampling designs, a sampling cage with mesh the same size as the travelling screens was installed in the exiting portion of the sluiceway to collect all debris and organisms that were impinged on the travelling screens for the duration of the sampling periods. If the cage became full, it was removed and replaced by a cage of the exact same design. Once a sampling period was completed, the sampling cage was lifted from the sluiceway and the contents were labelled with the time and date of collection. The samples were then sorted and enumerated by species and life stage. The sorting and identification process for the impingement study was not explained in the main document or the original impingement report.

After identification was complete, length (fork and/or total, as appropriate), weight, life stage (adult, juvenile), general health, and condition (live, recently dead, or long dead) were recorded for fish species. For invertebrates, carapace width (crabs), shell height and width (bivalves), and weights (hard-shelled invertebrates and squid) were recorded.

Impingement Data Quality Assurance and Control

Data quality assurance and control measures (QA/QC) for the impingement study were not discussed by the authors in the impingement report or within the self-assessment report (EcoMetrix 2017). The same level of data QA/QC should have been carried out for the impingement study as was detailed in the entrainment study. An independent checking of the sample sorting and specimen identification procedures would improve the confidence in the reported data.

Impingement Strengths and Limitations

The authors indicated the sampling design for the impingement study was selected to capture the seasonal cycles in organism abundance by sampling over the course of the year. Both of the sampling designs employed by the impingement study ensured that species with diel migration patterns were available in the impingement sampling. The longer soak time of the screens during the second, modified sampling design was identified by the authors as a deviation from best practices (EPRI 2004). One limitation of the 7-day composite, when compared to the initial sampling design of two 12-hour sampling events (day/night), was the inability to resolve diel patterns in impingement. Although low levels of deterioration were reported, potential data loss resulting from longer soak times may have occurred from the deterioration of impinged organisms. Smaller organisms may have broken down over the seven days and been lost through the mesh screens. Additionally, as more organisms are impinged upon the screens across the 7-day sampling period, the functional size of the mesh decreases. This would change the probability of impingement for small organisms during the week-long soak time and may not be reflected in the samples collected due to the mesh size of the sampling cage.

The mesh size of the sampling cage and the travelling screens are the same, which may lead to a bias in the size and amount of sampled organisms. If an object with a width less than the mesh size and a length greater than the mesh size is caught on the travelling screen, it could be missed by the sampling cage. Furthermore, as the functional mesh size of the travelling screens decreases over the 7-day sampling period, smaller organisms may not be captured by the sampling screen.

In addition to the issues discussed in the self-assessment report (EcoMetrix 2017), another possible source of data loss and misattribution was the availability of impinged organisms to other partially impinged organisms (e.g., Rock Crab) as prey. These animals, over the 7-days, would have opportunity to break down or ingest impinged organisms on the screens, possibly reducing the number and quality of observed specimens when the impingement sample was collected.

The authors also stated that sampling frequency was limited by site access and safety restrictions. The number of screens that could be manually washed per sampling event (four of eight) was also presented as a potential weakness of the study. The proposed limitations in sample frequency, and screen washings per day resulting from the modified 7-day sampling design are not expected to alter the study conclusions.

Entrainment

Entrainment Field Methods

All entrainment field methods described herein are based on information reported in the Ecometrix (2017) and Arcadis reports (Arcadis 2016a,b). There are aspects of the methodologies that would benefit from a more detailed description to enable a thorough evaluation of best practices. All entrainment samples were collected, using pump-in-net-in-tank setup, from the forebay of the cooling water system between October 16, 2014, and October 31, 2015, for a total of 102 samples, with increased sampling effort from May to June 2015. Water was pumped from the forebay using a three-inch trash pump (open-vane impeller). The intake for the pump-in-net-in-tank system was located in the first two metres of the water column. The pump discharge pipe was attached to a 0.5 m diameter plankton net (363 µm mesh), which was suspended in a large tank. Water from the forebay was filtered through the plankton net, with entrained debris and organisms being captured in the net. Damage to the eggs and larvae was minimized by piping the water through a diffuser before the water entered the plankton net and by submerging the plankton net in a tank of water. Once the water had filtered through the plankton net, the water could drain from the tank back into the forebay. The pump-in-net-in-tank system was located on a concrete bridge that spanned the forebay. Entrainment sampling was conducted in the forebay due to operational limitations of sampling water once it had already passed through the travelling screens. Water was pumped from the upstream side and drained from the tank on the downstream side of the bridge. An ultrasonic flowmeter was used to measure the flowrate of water through the sampling system. Flowrate could then be used to calculate volume of water sampled over a sample period. Finally, environmental data including water temperature and salinity were measured during each sample.

Samples were obtained over a 4-hour window encompassing the two hours before and after high tide either during the day or night. Day and night samples were at least 12 hours apart but were not at a set time of day due to the shifting semidiurnal tidal cycle at Point Lepreau; however, day samples always occurred during daylight hours and night samples occurred at dark. The majority of samples during each month occurred consecutively (i.e., two night samples followed by two day samples, or vice versa). Table 2.3 in the entrainment document indicates the sampling frequency for each month (Arcadis 2016b).

After each 4-hour sampling period, the plankton net was removed from the tank and all debris and organisms that were filtered from the water were collected in a one-litre opaque sample jar with a solution of 5% formalin. The sorting and identification of samples were carried out by personnel trained by the Huntsman Marine Science Centre (HMSC). Samples were drained and large debris removed, then small amounts were placed into petri dishes. The petri dishes were placed on a grid pattern to easily retrieve and enumerate eggs and larvae. General counts of fish eggs and larvae were conducted as well as some invertebrates such as lobster, shrimp, crab, and squid. Specimens were then placed in glass vials labelled with the collection date for identification. Meristic, morphological, and pigmentation patterns were used for identification of eggs and larvae. Eggs were sorted into four developmental stages and the total number of eggs in each stage were recorded. Eggs sorted into stage one were not identifiable. Larvae were sorted and enumerated by species, and total/notochord lengths were recorded.

Entrainment Data Quality Assurance and Control

All field observations were recorded on field data sheets, then backed up in an electronic format. All field sheets and electronic copies were reviewed by Arcadis personnel prior to being incorporated into the final dataset. Daily records were taken of observations, conditions, and events that could have affected the collected data. Additionally, two site visits were conducted by Arcadis supervisors to observe sampling procedures (September 2014 and October 2014).

For data QA/QC of sorting and identification of the entrainment samples, 10% of the samples were re-picked by personnel at the HMSC and approximately 40% of the samples were re-checked for accurate identification. Samples that were re-checked included all larvae collected between October 17, 2014, to May 8, 2015, and 23.5% of samples with eggs and larvae from May 13, 2015, to October 29, 2015. Corrections made by HMSC can be found in Appendix A of the entrainment document (Arcadis 2016b).

Entrainment Strength and Limitations

Similar to the impingement study, the authors designed the entrainment study to capture seasonal cycles in organism abundance by sampling over the course of a year; however, unlike the 7-day composite samples used by the impingement study, the separation of day and night sampling in the entrainment study meant that diel variability could be resolved.

The entrainment sampling assumes the timing of sample collection, both daily and interannual, captures the changes in egg and larvae availability in the water column. Many larval species undergo vertical migrations through the water column (e.g., Atlantic Herring; Stephenson and Power 1988), and the authors' decision to separate samples into day and night to assess diel patterns in ichthyoplankton presence was considered a strength of the study design. To account for interannual changes, sampling occurred every month with increased frequency during the spring and summer when eggs and larvae are most prevalent. Unfortunately, the sampling tended to be clustered, leaving large gaps of time (up to 28 days) where no data were collected. Spikes in eggs and larvae availability due to spawning events may not be captured with the current sampling protocol. A more detailed discussion of appropriate experimental units and ways to improve estimated losses for future studies can be found in the Section entitled "Extrapolation from Counts to Annual Estimates of Impingement and Entrainment".

A second assumption in the entrainment sampling, identified by the authors, was a well-mixed forebay. All samples were collected from the same location in the forebay, within the upper two metres of the water column. Because the volume of water sampled (30–80 m^3) is a very small fraction of the daily flow through the cooling water system (approx. 2.3 million m^3), small changes in the frequency of capture could have had large consequences to the estimated losses (see Extrapolation from Counts to Annual Estimates of Impingement and Entrainment for more detail). In addition, the lack of sample variance characterization could have been addressed by replication. The Ecometrix (2017) report acknowledges that a well-mixed forebay would be "a major assumption at most CANDU facilities", so any flow that may cause organisms to aggregate near the collection pump would increase the reported loses. Conversely, if flow directs organisms away from the collection pump, the reported entrainment losses would be underreported. An assessment of the distribution of organisms in the forebay should be considered in future studies at this site. Because the distribution is currently unknown, example calculations of uncertainty in this document do not include bias in the raw data, although it may have a considerable impact on the estimated losses.

A third assumption of the sampling design is the pump flows and impellor design do not damage the organisms.

The benefits and limitations of the pump-in-net-in-tank method and the standard tows with plankton nets were compared in the entrainment report (Arcadis 2016b). The pump-in-net-in-tank method was chosen since the volume of water sampled could be determined more accurately and sampled over a longer period of time. One potential limitation of both methods that is not discussed, is that sampling occurred in the forebay of the CW system, before organisms had the opportunity to be impinged upon the trash racks or travelling screens. Additionally, the size of the trash pump used in the pump-in-net-in-tank method (three-inch diameter) resulted in the collection of organisms that were potentially large enough to be impinged and therefore were erroneously attributed to the entrainment study.

Sources of Uncertainty: Raw Data Processing for Analysis

There are four main sources of uncertainty associated with sample processing. The first, identified by the authors in EcoMetrix (2017), is the assumption that all organisms in the sample were alive when captured and would not have survived passage through the CW system. The authors correctly treat this assumption as two separate issues. The authors suggest a live-dead determination of organisms in the water column before passage through the system, to determine ambient background mortality. While this adjustment would improve the estimated losses, it is likely a minor issue relative to the other sources of uncertainty in the study and it is not unreasonable to treat all entrained/impinged organisms as alive prior to entering the facility. The authors also provide several sources (e.g., Bamber and Seaby 2004) to suggest that survival through the CW system is possible, and even likely for some species (> 50%), especially invertebrate species, and could be explored in future studies.

The second source of uncertainty in the impingement and entrainment studies (mostly impacting the entrainment study) was the prevalence of unidentified species, primarily eggs. The authors discuss that approximately 80% of the entrained eggs could not be identified. They applied two approaches to allocate the unidentified eggs. First, the eggs were proportionally allocated among the identified groups/taxa. Second, the eggs were allocated by professional judgement on which species was dominant on the day of collection. Both datasets were compared using the age-1 equivalent models. This resulted in relatively little change in the number of age-1 equivalents according to the authors. Although two different methods were explored, both methods for allocation of unidentified eggs assume unidentified eggs are one of the identified species. Neither method considers how to partition eggs to species that were not identified in the study. The BoF is home to a larger range of species than those identified. The impact on species not identified in the study could be considerable due to the large percentage of unidentified eggs and each sampled egg representing approximately 20,000 entrained organisms. Only a small portion of other life stages were unidentified to species (< 0.1% of impinged fish, 1.6% of entrained larvae).

The third source of uncertainty is the misidentification of the life stage of each organism, primarily juveniles identified as larvae. The authors provided minimum, maximum, and average total lengths for each species of fish identified as larvae in the entrainment report (Arcadis 2016b). Many of these fish were > 25 mm and up to 55 mm, which should classify them as juveniles. This misidentification impacts the analysis by applying the incorrect natural mortality rate; juveniles tend to have a lower natural mortality rate compared to larvae. Additionally, misclassification of an individual as a larva would incorrectly apply natural mortality for the preceding age class twice, as it had already survived past that stage. For example, if survival is calculated as larvae → juveniles → age-1 and there is 50% survival between each age class, you would expect 100 juveniles to produce 50 age-1 adults. If 100 juveniles are incorrectly classified as larvae, then survival to age-1 drops to 25. Erroneous identification of life stage could vastly underestimate survival to age-1. Considering many species were estimated to have millions of larvae entrained, the true value could be off by orders of magnitude.

The final source of uncertainty pertaining to data processing is the presence of large (> 25 mm) organisms in the entrainment samples that would likely not be included if entrainment sampling had occurred downstream of the screens. Entrainment sampling occurred in the forebay upstream of the trash racks and travelling screens using equipment (three-inch diameter pump) that could capture organisms that would otherwise be impinged. Due to the difference in sample volume between the impingement and entrainment studies, a single organism in the impingement study may represent two or three total impinged organisms, while a single organism in the entrainment study may represent 15,000 to 20,000 individuals per day. It is likely that due to their size, some of the larvae identified in the entrainment study, such as a 55 mm White Hake, would have been impinged. The extrapolation method, described below, would attribute an entrainment of almost 17,000 individuals per day to the one sampled specimen, but no White Hake were identified in the impingement study. The large discrepancies in losses indicated by the two studies may be indicative of a sampling design issue.

Field Methods Conclusions

The equipment chosen to sample both impingement and entrainment provided the minimum amount of data required to address the impact of the cooling water system on the fauna. Efforts to quantify the level of impact would have benefitted from a more rigorous sampling design, including a measure of variability. The sampling design used for both studies was adequate for assessing seasonal and, in the case of entrainment, diel patterns. However, the temporally clustered and sometimes infrequent nature of sampling for the entrainment study, particularly during the winter, may be insufficient to capture the intra-annual variation in abundance and species composition. Furthermore, the authors stated that multiple years of impingement and entrainment data would be necessary to resolve interannual patterns in abundance and species composition. A major assumption of the entrainment study was that the forebay is treated as well mixed, a violation that may introduce considerable bias in the estimated losses. There is no information available on the potential magnitude nor direction of this bias.

Although the assumptions the authors made pertaining to the collection and processing of data were reasonable, several sources of uncertainty may have impacted the estimated losses and its associated population-level impact. These include: the assumption that all organisms in the sample were alive when captured and would not have survived passage through the CW system; the prevalence of unidentified species, primarily eggs; the misidentification of the life stage of each organism, primarily juveniles identified as larvae; and the large discrepancies in losses between the impingement and entrainment studies.

Are the analytical methods used to evaluate impingement and entrainment consistent with best practice?

Raw count data collected during the impingement and entrainment studies were extrapolated to provide an estimate of annual losses of the number of fish impinged, and eggs and larvae entrained at the PLNGS. These annual estimates were then used as the input for three models intended to provide an estimate of losses of age-1, production foregone, and fisheries yield due to the PLNGS. This section describes the methods and uncertainty surrounding the extrapolation from the raw data to annual estimates of impingement and entrainment, and provides an overview of the application of the three models and identify concerns.

Extrapolation from Counts to Annual Estimates of Impingement and Entrainment

Summary of Extrapolation Methods

Annual estimated losses from both impingement and entrainment were referred to by the authors as the “flow-corrected annual estimates”, although it is unclear why this correction was applied to the raw impingement data. The methods described prior to applying the flow correction should result in data that represent all impinged organisms over the course of the study. No description of the flow correction method was provided, and therefore cannot be reviewed. The “flow-corrected” estimates of impinged organisms were roughly double that of the raw data for most species (e.g., 3,108 Northern Shrimp impinged with an estimated 6,206 total annual impingement).

Unlike the impingement study, the extrapolation of counts from the entrainment study were very large (e.g., 1,979 Northern Shrimp larvae were found in the samples and extrapolated to over 230 million).The PLNGS has an intake of approximately 2,332,800 m^3 of water per day, while the majority of samples filtered around 60 to 80 m^3 of water, meaning for each organism identified in the sample, approximately 15,000 to 20,000 organisms were considered to be entrained during the 12-hour period that the sample represents. Annual flow-corrected estimates for the entrainment were calculated separately for day and night, with each period considered to be 12 hours. On days that sampling occurred (4 to 12 times per month), a daily estimate of the total number of organisms passing through the station was calculated by multiplying the standardized number of organisms per m^3 by 50% of the total daily intake volume. Together, one day and one night was considered to be 100% of the station's daily intake volume. There were 52 day samples and 50 night samples collected between October 2014 and October 2015. On days with no sampling, an estimate of daily entrainment was calculated as a weighted average of the numbers of organisms on the closest sampling days both before and after, with weights assigned based on the number of days between the day sampling took place and the day to be estimated.

Uncertainty in Extrapolation

The estimated numbers of fish expected to die annually provided in the self-assessment are reported as single values without any measure of the uncertainty (i.e., estimate precision). Within this section, uncertainty is discussed in terms of numeric uncertainty, rather than sources of uncertainty previously described for the processing of data for field methods. Common measures of uncertainty include the standard error of the estimate or the confidence interval, which allows for the interpretation of the estimate with an indication of the amount of variability between repeated experiments. This approach, known as “point and interval estimation” evaluates how close the estimate might be to the true value.

Both sample volume and frequency were limited by operational requirements, and therefore the extrapolation from the number of organisms in the sample to annual estimates of losses has the potential to include a high level of uncertainty. Due to the low number of sample days, high uncertainty would be included with the estimated losses on days where no samples were collected. Gaps between sampling days were as long as 28 days during winter months and up to 20 days in the spring/summer, when larval presence was highest. Using a weighted average between two sampling days assumes that the ichthyoplankton availability is a linear trend between the two closest sampling days. The longer the gap between sampling days, the more likely this assumption will be violated due to the potential mismatch between sampling events and the reproductive schedule of a species.

Future study designs would benefit from a stratified random sampling approach where random samples are taken within a designated stratum (i.e., set time frame; e.g., Kumar and Griffith 1977). Appropriate strata should be chosen so that variability within a stratum is less than between strata; these strata should be chosen before data are collected, rather than applied on a post-hoc basis. Although it is not the preferred method, for illustrative purposes a post-hoc stratification was applied to the Atlantic Herring data collected during the entrainment study to provide a measure of uncertainty surrounding the reported losses in the self-assessment. The study year was split into two week-long strata, with the exception of January, February, and October 2015, where each month as a whole was considered a single stratum due to limited sampling events during those months. The average number of organisms per day was calculated for each strata following the extrapolation method described in the previous section (number of organisms/sample volume × total daily water volume), along with the standard error and variance. The mean daily entrainment was then multiplied by the number of days in the strata to obtain a total entrainment estimate for the strata. Strata were summed to obtain the annual estimate and confidence intervals were calculated using methods outlined in Nelson (2006). The self-assessment reports a loss of 1,281,942 Atlantic Herring larvae. The post-hoc stratification method described above provides an estimate of 1,409,952 ± 907,383. While the total numbers from each method are similar, the post-hoc stratification illustrates the potentially large degree of uncertainty surrounding the reported loss. As discussed in previous sections, this calculation does not include other sources of uncertainty, such as bias due to an unmixed forebay.

The calculation discussed above is included to provide an example of adding a measure of uncertainty to the existing mortality estimates, but is not being suggested as a replacement method. The data used in the extrapolation calculation are highly zero-inflated, which the above method does not account for and therefore may not be appropriate. For example, Atlantic Herring larvae were only observed in 9 of 102 entrainment samples. Selecting an appropriate experimental unit and stratification scheme will be important for improving estimation of losses in future studies. Strata should be short enough to limit variability of samples within each strata, but long enough to not impose an unrealistic sampling frequency. Care should also be taken in regards to the experimental unit. Sampling is limited by operational requirements at the site, but a series of shorter samples may be more beneficial than one long sample as it will improve estimation of variability.

Equivalent Age Models, Production Foregone Models, and Equivalent Yield Models

Model Overviews

The three models selected to assess losses at the PLNGS are standard models used to estimate future impacts arising from the loss of eggs and larvae at power generating stations. They have been applied at facilities across the United States for multiple species, as the models require only an estimate of stage-based mortality and growth and not site-specific data (EPRI 2004). The selection of these models for this study is appropriate and considered best practice. All three models provide a useful metric to compare losses across species in units that are easier to interpret than the loss of eggs and larvae; however, the limitations and assumptions of each model should be considered when interpreting the results. Detailed descriptions and model equations can be found in EPRI (2004).

Equivalent age models (EAMs) are used to calculate the number of individuals from each age class that survive to a specific age, called the age of equivalence, summed across ages to provide a single estimate of losses. In this study, age-1 was selected as the age of equivalence. Age-1 equivalents were calculated for 15 species captured during the impingement and entrainment studies at the PLNGS (Table 1). For eggs, larvae, and juveniles this is a forward projection, but for fish older than age-1 equivalent losses are hindcast as the inverse of the survival rate. Barnthouse et al. (2019) recommend against the use of EAMs to backwards project the loss of fish older than the age of equivalence, as it can inflate the losses by attributing all sources of mortality to impingement or entrainment. For this study, the majority of losses were eggs, larvae, or juveniles; very few fish > age-1 were included in the losses; therefore, the additional mortality attributed to the station due to this backwards projection bias would be minimal.

Production foregone models are applied to forage species to estimate the loss of future growth, informing prey availability, that may indirectly affect commercial species. Production foregone models require information on survival between age classes as well as the growth rate and average weight for each age class. Production foregone, reported as kg, was calculated for four forage species caught at PLNGS (Table 1).

Equivalent yield models (EYMs) are used to calculate the fisheries yield that impinged or entrained individuals would have contributed had they survived. Yield is calculated based on a modified Baranov's catch equation. Equivalent yield was calculated for 11 species (Table 1).

Species selection for models

Only a portion of species that were observed during the impingement and entrainment sampling were selected for analysis using the EAM (Table 1). Subsequently, depending on whether a fishery existed, species were included in either the production foregone modelling or the EYM. The rationale behind the initial species selection for the EAM and subsequent models was not well defined by the authors. Several species that support CRA fisheries in the BoF or southwest Nova Scotia were identified during sampling, but in such low numbers they were not included in the EAMs or EYMs. Species that were impinged or entrained but not included in either model can be found in Table 2.

Table 1. Species included in the equivalent age model (EAM), production foregone, or equivalent yield model (EYM) from the Point Lepreau Generating Station self-assessment (EcoMetrix 2017). Dashes indicate the model was not used for that species. Production foregone was calculated for forage species only and equivalent yield was calculated for commercial, recreational and Aboriginal species only.

Common Name	Scientific Name	EAM	Production foregone	EYM
American Lobster	*Homarus americanus*	X	-	X
American Plaice	*Hippoglossoides platessoides*	X	-	X
Atlantic Cod	*Gadus morhua*	X	-	X
Atlantic Herring	*Clupea harengus*	X	-	X
Blackspotted Stickleback	*Gasterosteus wheatlandi*	X	X	-
Fourbeard Rockling	*Enchelyopus cimbrius*	X	X	-
Northern Shrimp	*Pandalus borealis*	X	-	X
Rainbow Smelt	*Osmerus mordax*	X	X	-
Red Hake	*Urophycis chuss*	X	-	X
Rock Crab	*Cancer irroratus*	X	-	X
Rock Gunnel	*Pholis gunnellus*	X	X	-
Shorthorn Sculpin	*Myoxocephalus scorpius*	X	-	X
Silver Hake	*Merluccis bilinearis*	X	-	X
Windowpane Flounder	*Scopthalmus aquosus*	X	-	X
Winter Flounder	*Psuedopleuronectes americanus*	X	-	X

Model Selection and Application Strengths and Limitations

There are four areas of concern with the selection or use of the three models used in the PLNGS study. First, the use of a correction factor (i.e., too large or small) that could bias the estimated losses. The three age/stage-based models assume that all organisms classified as one life stage (e.g., larvae) are at the beginning of that stage. To correct for this bias, the authors applied a survival correction to the stage the organism was classified as when it was collected. For example, when calculating the age-1 equivalents for eggs, the survival correction was applied to the survival between eggs and larvae, but not for the survival between larvae and juveniles or juveniles and age-1. This correction factor is discussed in detail in EPRI (2004). The use of a correction factor increases survival between stages, as it assumes that some individuals are not at the beginning of the life stage and the probability of surviving to the next life stage is increased. By not accounting for this increased survival, the model will underestimate losses attributed to the PLNGS. Conversely, applying too large of a correction will inflate the estimated losses. Second, model parameters are treated as known and fixed. This is unlikely and is discussed within the “Sources and Selection of Appropriate Life History values section. Third, the use of these three models to assess losses from impingement and entrainment does not consider the loss of the reproductive potential associated with those organisms. An additional analysis to address this loss of future productivity would be useful. Finally, the reported losses from the analysis are presented with minimal context. The authors present a table of fisheries landing from the Maritimes Region, which provides an overview of fishing pressure on some of the species identified in the study. A more thorough review of losses relative to the overall population size or local fisheries would be beneficial. The significance of the reported losses is discussed in the “Significance of reported Mortality” section.

Analytical Methods Conclusions

The analyses completed to calculate losses at the PLNGS are practical given the operational limitations of the study, but that does not negate the issues introduced by low sample numbers and the lack of characterization of variance. Changes to future study design to increase sampling frequency, incorporate random sampling with stratification and a more complete measure of uncertainty would be beneficial. An additional model to evaluate the lost reproductive potential of impinged or entrained individuals would be helpful when evaluating losses at the PLNGS. There are limitations associated with the extrapolation of raw data to the flow-corrected annual losses presented in the document due to the low sample volume, low sample frequency and zero inflation in the data. A more robust study is required to address the magnitude and direction of the potential bias in the presented results and therefore this Science Response can only provide a critique of the presented results and not a correction.

Is the Species List Representative of the Commercial, Recreational, and Aboriginal Species in the Area?

Overview of Fish Communities in the Bay of Fundy

The BoF is home to a diverse fish community, many of which are fished commercially, recreationally, or fall under SARA listing/COSEWIC designation (Dadswell and Rulifson 2021). Dadswell and Rulifson (2021) identified 85 fish species that are known or suspected to inhabit the inner BoF. It is reasonable to expect similar species, or a subset thereof, to be present in the waters surrounding Point Lepreau. Ichthyoplankton surveys can further inform the diversity of species and life stages in the area. Ichthyoplankton surveys of Passamaquoddy Bay and Saint John Harbour, areas close to Point Lepreau, from 2011 to 2014 observed 32 species of fish eggs and larvae (Van Guelpen et al. 2021). Four of these species were not included in the 85 species listed in Dadswell and Rulifson (2021).

Using fishing landings records from the Northwest Atlantic Fisheries Organization (NAFO) subdivision 4Xs,,accessed from the Maritimes Fisheries Information System (MARFIS) database, an additional eight fish species were identified, although many were large pelagic species. Thirteen of the commercial species were reported in very low numbers and are expected to have a low probability of encountering the PLNGS. Commercial catch data for NAFO 4Xs do not include freshwater fisheries for diadromous species, such as Alewife, Blueback Herring, Rainbow Smelt, American Eel, Striped Bass, and American Shad, which may be seasonally present around the PLNGS. In additional to the seasonal changes in species composition and abundance of adults, ichthyoplankton abundance fluctuates with large peaks of short duration in the summer months (Van Guelpen et al. 2021).

Fish Species identified at Point Lepreau

The impingement study identified 38 species of fish and 25 species of invertebrates, while the entrainment study identified 24 species of fish eggs and larvae, and 4 species of invertebrates. The early-stage eggs that could not be identified to the species level were grouped as CYT (Cunner and Yellowtail Flounder) or H4B (Gadid and Merluccid hakes, Rocklings, Butterfish, Windowpane and Gulf Stream Flounder). Van Guelpen et al. (2021) used the same groupings when processing ichthyoplankton survey samples from Passamaquoddy Bay and Saint John Harbour. A substantial portion (80%) of the fish eggs could not be identified and were distributed proportionally across the positively-identified fish species. In total, 47 fish species and 25 invertebrate species were observed across the two studies (Table 2). Nine of the fish species identified in the self-assessment document were not included in the species lists from Dadswell and Rulifson (2021), Van Guelpen et al. (2021) or the commercial catch records. Fifty-nine species identified as part of the fish community in the BoF were not identified at Point Lepreau.

*Table 2. Species observed in the impingement and entrainment studies at the Point Lepreau Generating Station. *Species included in the equivalent age model in the self-assessment report.* ***Bolded*** *species were recorded in the Maritimes Fisheries Information System database (2011–2021) or have an associated freshwater fishery.*

Common Name	Scientific Name
Acadian Hermit Crab	*Pagurus acadianus*
Alewife (Gaspereau)	***Alosa pseudoharengus***
Alligatorfish	*Aspidophoroides monopterygius*
American Lobster*	***Homarus americanus***
American Plaice*	***Hippoglossoides platessoides***
American Sand Lance	*Ammodytes americanus*
Arctic Alligatorfish	*Aspidophoroides olriki*
Atlantic Cod*	***Gadus morhua***
Atlantic Herring*	***Clupea harengus***
Atlantic Hookear Sculpin	*Artediellus atlanticus*
Atlantic Mackerel	***Scomber scombrus***
Atlantic Seasnail	*Liparis atlanticus*
Atlantic Silverside	*Menidia menidia*
Atlantic Spiny Lumpsucker	*Eumicrotremus spinosus*
Barnacle	*Balanus* spp.
Blackspotted Stickleback*	*Gasterosteus wheatlandi*
Blue Mussel	*Mytilus edulis*
Butterfish	*Peprilus triacanthus*
Capelin	*Mallotus villosus*
Common Periwinkle	*Littorina littorea*
Common Sea Star	*Asterias rubens*
Cunner	*Tautogolabrus adspersus*
Daubed Shanny	*Leptoclinus maculatus*
Finger Sponge	*Chalina* spp.
Fourbeard Rockling*	*Enchelyopus cimbrius*

Common Name	Scientific Name
Gelatinous Seasnail	*Liparis fabricii*
Glacier Lanternfish	*Benthosema glaciale*
Green Crab	***Carcinus maenas***
Green Sea Urchin	***Strongylocentrotus droebachiensis***
Grubby	*Myoxocephalus aenaeus*
Gulf Snailfish	*Liparis coheni*
Haddock	***Melanogrammus aeglefinus***
Inquiline Snailfish	*Liparis inquilinus*
Lion's Mane	*Cyanea capillata*
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*
Lumpfish	*Cyclopterus lumpus*
Monkfish (Goosefish)	*Lophius americanus*
Moon Jelly	*Aurelia aurita*
Mummichog	*Fundulus heteroclitus*
Northern Pipefish	*Syngnathus fuscus*
Northern Red Anemone	*Urticina felina*
Northern Shortfin Squid	***Illex illecebrosus***
Northern Shrimp*	***Pandalus borealis***
Nudibranch	*Dendronotus frondosus*
Orange-footed Cucumber	***Cucumaria frondosa***
Pollock	***Pollachius virens***
Radiated Shanny	*Ulvaria subbifurcata*
Rainbow Smelt*	***Osmerus mordax***
Red Hake*	***Urophycis chuss***
Rock Crab*	***Cancer irroratus***
Rock Gunnel*	*Pholis gunnellus*
Sea Gooseberry	*Pleurobrachia bachei*
Sea Raven	*Hemitripterus americanus*
Sea Scallop	***Placopecten magellanicus***
Sea Spider	Pycnogonida
Shorthorn Sculpin*	*Myoxocephalus scorpius*
Silver Hake*	***Merluccius bilinearis***
Smooth Skate	*Malacoraja senta*

Common Name	Scientific Name
Snakeblenny	*Lumpenus lampretaeformis*
Soft-shell Clam	***Mya arenaria***
Thorny Skate	*Amblyraja radiata*
Toad Crab	*Hyas coarctatus*
Tomcod	*Microgadus tomcod*
Tortoiseshell Limpet	*Tectura testudinalis*
Tunicate	*Ascidia obliqua*
Waved Whelk	*Buccinum undatum*
White Hake	***Urophycis tenuis***
Windowpane Flounder*	*Scophthalmus aquosus*
Winter Flounder*	***Pseudopleuronectes americanus***
Witch Flounder	***Glyptocephalus cynoglossus***
Wrymouth	*Cryptacanthodes maculatus*
Yellowtail Flounder	***Limanda ferruginea***

The dominant species identified in entrainment samples at the PLNGS, matched the species composition from Van Guelpen et al. (2021). The highest densities (larvae or eggs per m^3) of these species observed in the entrainment study at PLNGS were within the ranges observed in Passamaquoddy Bay and Saint John Harbour (Van Guelpen et al. 2021); however, the densities observed at PLNGS were usually at the lower end of these ranges and sometimes far below the highest observed densities reported by the other ichthyoplankton surveys (Van Guelpen et al. 2021).

CRA, SARA, and COSEWIC Species

Approximately 23 species (exact numbers depends on how species are grouped) that may support CRA fisheries were captured during impingement and entrainment sampling at the PLNGS. Eleven of these CRA species were included in the equivalent age models and the self-assessment report provided species descriptions for eight of those species: Atlantic Herring, Atlantic Cod, Red Hake, Shorthorn Sculpin, Winter Flounder, American Lobster, Rock Crab, and Northern Shrimp. The descriptions provided an overview of physical characteristics, life cycle, range, and any existing fisheries in the Maritimes Region, albeit without sources. The criteria that the authors used to select species that were described in detail was not provided. Commercial landings from DFO’s Maritimes Region in 2014 were also presented by the authors (EcoMetrix 2017; Table 8.8) for supplementary contextual information on species that did not have a species description included in the report. The authors also provided detailed descriptions for four forage species (Rainbow Smelt, Fourbeard Rockling, Blackspotted Stickleback, and Rock Gunnel) and Harbour Seals.

Twelve CRA species were identified in very low numbers at the PLNGS and were not included in any of the presented calculations of the estimates of losses. Of these species, Scallop (*Placopecten magellanicus*), may have warranted inclusion in the analyses as they support a large, valuable fishery in the area (DFO 2021c). Additionally, there were several CRA species such as American Eel, redfish, and Striped Bass that were not identified during impingement or entrainment sampling that may have been in the area surrounding the PLNGS. Potential reasons for these zero records are discussed below. In addition to CRA species, the authors identified seven species listed under SARA or designated by COSEWIC that were captured in very low numbers, or in the case of Atlantic Salmon, zero. The only species with a COSEWIC designation that was captured but not listed by the authors was lumpfish.

Species with No Reported Losses

Many of the fish and invertebrate species that were reported by Dadswell and Rulifson (2021), Van Guelpen et al. (2021), or within the DFO commercial catch records were not observed in the impingement or entrainment studies at the PLNGS. Reasons for this can be partitioned into two broad categories. First, there was zero probability of impingement or entrainment (true zero). Species that are known to be present in the outer BoF may not frequent the near-shore environment and will not encounter the CW system intake, such as large pelagic species like tuna and certain sharks. This also pertains to the early life stages of species whose spawning grounds are not in the vicinity of the PLNGS. If large pelagic species do encounter the CW intake system, they are capable of swimming at much greater velocities than the flow into the CW intake, therefore avoiding the intake current altogether.

Second, species that are present in the area and unable to avoid the intake current may be impinged or entrained but not identified during sampling. In the impingement and entrainment studies, this Science Response identifies four ways these false zeros may be introduced. First, some animals may be large enough to become impinged on the trash racks that are located upstream of the travelling screens and are not included in the impingement study. It is not stated in the self-assessment report whether organisms becoming impinged on the trash racks is a persistent issue. Second, early life stages of species that are present in low densities may avoid being sampled in the entrainment study due to low sampling frequency and the small volume of water being filtered. Third, the timing of sampling for the entrainment study may miss short duration increases in egg and larvae availability. For example, larval American Eels were not observed during the entrainment study, although they are known to be present near shore in the winter. Sampling for the entrainment study occurred infrequently during the winter and may have missed the migration of larval eels due to the short time period that eels would be expected to be present. Finally, captured species may have been misidentified. This is unlikely for older age-classes of common species, but may have occurred with stage-1 eggs that were collected during the entrainment study, or extremely small organisms.

Species List Conclusions

There is a diverse fish community in the area surrounding Point Lepreau and in total, 47 fish species and 25 invertebrate species were observed during impingement and entrainment sampling. Many of these species are considered to be CRA species and may support fisheries in the BoF or surrounding areas. Eleven CRA species were included in the equivalent age models, with an additional twelve CRA species captured in low numbers but not included in any of the assessment models. Scallop may have warranted inclusion in the analyses as they support a very large, valuable fishery in the area (DFO 2021c). Additionally, there were several CRA species such as American Eel, redfish, and Striped Bass that were not identified during impingement or entrainment sampling that may have been in the area surrounding the PLNGS. Species that are able to actively avoid the CW intake would unlikely be impinged or entrained; however, it is possible that species were entrained and missed during sampling due to low sample volume and frequency.

Are the Population Units and Life History Values Used in the Analysis Applicable to the Species?

The models used in this study required stage/age-specific life history values for each species to calculate the age-1 equivalents, production foregone, or equivalent yield. Information on age specific mortality rates, fishing mortality rates, the fraction of each age class vulnerable to the fishery, and the average weight-at-age were presented for the 15 species included in at least one model. The production foregone models also required age-specific growth; however, this information was not presented. Population units were not discussed in the self-assessment but a discussion of the significance of the reported mortality and its impact at the population level is included in Significance of Reported Mortality section.

Sources and Selection of Appropriate Life History Values

For the majority of species in the self-assessment document, life history values were obtained from USEPA (2006), which presented values for populations and fisheries in the northeastern United States. For American Lobster, life history values were obtained from primary literature sources (Wilder 1953, Fogarty and Idoine 1986, Gendron and Gagnon 2001). Rock Crab data were an aggregation of all commercial crab species, and an aggregation of shrimp species was used in place of Northern Shrimp. Species-specific weight-at-age for both Rock Crab and Northern Shrimp were obtained from USEPA (2006) and from Skúladóttir (1996), respectively.

The authors acknowledge that life history data can be difficult to obtain, and the use of surrogate species information may introduce a bias into the modeling results. Information on life-history parameters is generally not available for the populations in the BoF specifically, so available data from the northeastern United States was used. For species, such as Atlantic Herring, BoF records are available to refine the life history parameters (e.g., Singh et al. 2020). Overall, the life history parameters used in the study were reasonable. The information from the USEPA (2006) report is easily accessible and an alternative to estimating BoF population life history characteristics directly, given the expected similarities between the BoF and northeastern United States. There are several species (e.g., Northern Shrimp) where the use of data from the northeastern United States is considered inappropriate. The values reported for Northern Shrimp in USEPA (2006) were an aggregate of data from Pacific shrimp species and likely underreport mortality (Hardie et al. 2018). In addition, fishing mortality-at-age, weight-at-age, and vulnerability to the fishery may also influence the final estimated losses. Currently, there is no commercial fishery in the BoF, but on the eastern Scotian Shelf, the commercial fishery is focused on mature females age-5+, with younger individuals caught incidentally. Identifying age and growth of Northern Shrimp, and therefore weight-at-age, is difficult to assess due to their life history (start as small males, transition to larger females) and dependence on environmental factors (Koeller 2006). Unlike other species in the self-assessment, Northern Shrimp were caught in very large numbers and modifications to the life-history parameters used in the EAM and EYM have the potential to result in large differences in reported losses.

Additional concerns with the life history-parameters include underreported weight for age-3 Atlantic Cod (0.628 lbs in self-assessment, 3.3 lbs from Nova Scotia records; Clark et al. 2015), and underrepresented age classes. In the USEPA (2006) document, Red Hake larvae were broken down by size; however, the mortality rate for each size was not aggregated for the self-assessment document, resulting in larval mortality being underreported. Although the life-history parameter values may be within the range of appropriate values for many species, the parameters are treated as both known and fixed within the models in this study. This can bias the final estimated losses, which cannot be corrected using a single value since true values are not known. Incorporating a measure of uncertainty in the parameter values can provide reported losses with a measure of error. This is discussed in detail in the next section.

Monte Carlo Simulation to Incorporate Uncertainty

Overview

Life -history parameters are treated as known and fixed; both assumptions that are unlikely to be true. When single values for parameters are used to calculate the model outputs, there is no measure of uncertainty surrounding the results. As previously indicated measures of uncertainty provide an indication of estimate precision. Unlike the extrapolation from raw data to annual estimates, where uncertainty in the final estimate can be calculated from the variability in the data, uncertainty in the model outputs is derived from characterizing uncertainty in the life history parameters. Instead of using fixed values for life-history parameters, a range of values can be used. Repeatedly selecting new parameters and recalculating the model output (e.g., number of age one fish) will result in a distribution of reported losses. Reporting the range of values, typically as the 2.5%, 50%, and 97.5% quantiles, provides a measure of uncertainty in the reported losses, instead of a single point estimate. This method is broadly known as a Monte Carlo simulation. Two examples of using a Monte Carlo simulation are presented below.

Uncertainty in Age-1 Equivalents

A Monte Carlo simulation was produced for the calculation of age-1 equivalents of entrained larvae for Atlantic Herring and Northern Shrimp. The number of age-1 equivalents is calculated by applying the total mortality rate at each life stage from the age of capture to age-1. For Atlantic Herring, 1,281,942 larvae were entrained, and the instantaneous larval and juvenile mortality rate was 3.26; resulting in 3,639 larvae surviving to age-1. For Northern Shrimp, 231,505,075 larvae were entrained, the instantaneous larval mortality rate was 3.4, and the instantaneous juvenile mortality rate was 0.14, resulting in 12,999,625 larvae surviving to age-1.

For the Monte Carlo simulation, larval and juvenile mortality rates were randomly selected from a uniform distribution with bounds ± 20% around the reported value. The age-1 equivalents were then calculated with the new parameter set. This was repeated 10,000 times and the 2.5%, 50%, and 97.5% quantiles were calculated and reported in Table 3. Modifications to the chosen distribution (e.g., normal vs. uniform) and its bounds will change the reported quantile range; a uniform distribution with bounds ± 20% around the reported value is a reasonable starting place for illustrative purposes.

Table 3. Age-1 equivalents for entrained larvae reported in the self-assessment document and 2.5%,50%, and 97.5% quantiles from a Monte Carlo simulation.

	Atlantic Herring	Northern Shrimp
From self-assessment	3,639	12,999,625
2.5% quantile	1,359	6,926,831
50% quantile	3,615	13,085,494
97.5% quantile	9,741	24,162,816

Propagation of Uncertainty

Uncertainty in the analysis can be incorporated at multiple stages since the methods used to calculate losses are dependent on previous calculations. Errors propagate through each step, increasing uncertainty in the final estimate. To illustrate this, the EYM was used as an example for both Atlantic Herring and Northern Shrimp. Three Monte Carlo simulations were performed, each with an additional source of uncertainty. The first simulation only incorporated error in the instantaneous natural mortality rate (M) and instantaneous fishing mortality rate (F) of individuals at or past the age of recruitment; the second simulation incorporated error in M for the equivalent number of age at recruitment, and finally, the third simulation incorporated the uncertainty from the extrapolation of raw data into annual estimates of larval losses.

In the EYM, the potential losses attributed to fishing are calculated for each age class of the lost cohort. This requires M and F for each age, starting at the age of recruitment (age-r). Like the Monte Carlo simulation for age-1 equivalents, sets of parameters ± 20% around the reported values were randomly selected from a uniform distribution 10,000 times and the equivalent yield was calculated for each iteration. The number of age-r individuals was considered fixed in this first simulation. Results from Simulation 1 are found in Table 4 and demonstrate how small deviations in the parameters affect the final yield calculation.

In Simulation 2, error in M of ages less than the age of recruitment (age-1 for Herring, age-3 for Northern Shrimp) was included in addition to the error in M and F of the recruited age classes. The annual flow-corrected estimate of entrained larvae was used as a fixed starting point in this simulation. New parameter sets were selected in the same way as Simulation 1. In Simulation 3, uncertainty in the annual flow-corrected number of entrained larvae was included in addition to error in M. The annual estimate of entrained larvae was randomly selected from a uniform distribution bound between the upper and lower confidence intervals calculated following the method described in the Extrapolation from Counts to Annual Estimates section. For Atlantic Herring, this was between 502,569 and 2,317,335, and for Northern Shrimp, this was between 189,859,775 and 263,826,560.

The results from the three simulations in Table 4 illustrate how increasing uncertainty in the parameters increases the uncertainty in the final estimate without major changes to the median estimate. The actual values presented in the table are not intended to replace the reported losses from the self-assessment document, but to provide an example of how to include a measure of uncertainty and how uncertainty compounds when there are multiple sources. In addition to the sources of uncertainty included in the simulation, there are others, such as the weight-at-age, which could be included and would further increase the estimated interval. Also, the distributions and associated parameters used in the simulation to randomize the life history parameters were conservative and only selected as an example of applying the Monte Carlo method.

Table 4. 2.5%, 50% and 97.5% quantiles from a Monte Carlo simulation for the calculated yield (in kg) of Atlantic Herring and Northern Shrimp. Simulation 1 adds uncertainty in the natural mortality rate (M) and fishing mortality rate (F) for age classes at or beyond the age of recruitment (equivalent yield model [EYM]). Simulation 2 adds in uncertainty in the natural mortality rate (M) for age classes below the age of recruitment (equivalent age model [EAM]), and Simulation 3 adds in uncertainty in the annual larval losses using the confidence interval calculated as part of the extrapolation from raw data to flow-corrected numbers. Minor corrections in the application of the EYM resulted in an estimated yield of 232 kg for Atlantic Herring and 37,000 kg for Northern Shrimp compared to the reported values from the self-assessment of 276 kg and 41,386 kg respectively. Values reported in the table reflect the corrected application of the model.

Species	Quantile	Yield (kg) Simulation 1 M and F for EYM	Yield (kg) Simulation 2 M and F for EYM M in EAM	Yield (kg) Simulation 3 M and F for EYM M in EAM Annual larval losses
Atlantic Herring	2.50%	199	66	45
Atlantic Herring	50%	232	227	238
Atlantic Herring	97.50%	269	792	1,106

Species	Quantile	Yield (kg) Simulation 1 M and F for EYM	Yield (kg) Simulation 2 M and F for EYM M in EAM	Yield (kg) Simulation 3 M and F for EYM M in EAM Annual larval losses
Northern Shrimp	2.50%	30,030	18,297	17,396
Northern Shrimp	50%	37,000	36,531	36,312
Northern Shrimp	97.50%	44,777	73,137	74,610

Life History Values Conclusions

For the majority of species, the life-history parameters used are appropriate and likely fall within an acceptable range for populations in the BoF. For some species, such as Atlantic Herring, BoF-specific parameters exist and could be refined. A limitation of the study is the treatment of life-history parameters as known and fixed within the models. Monte Carlo methods were used to illustrate how to add a measure of uncertainty to the final model output and how uncertainty in a multi-stage analysis propagates through each step. The examples provided use a simple criterion of ± 20% of the reported life history parameter as the bounds for the random selection of parameters for the simulation. While this is expected to buffer minor issues surrounding life-history parameters that can change slightly, both spatially and temporally, it does not correct for major deviations from the true value of the parameters. Uncertainty estimated from a Monte Carlo simulation will not overcome bias introduced due to the incorrect selection of a life-history parameter. The reported losses from the self-assessment report could be used to inform decisions regarding offsetting, but the values should not be treated as exact.

Significance of Reported Mortality

Determining the significance of reported mortality is challenging since it depends on many information sources some of which may not be available.

Reported Annual Losses from the Self-Assessment Document

The reported losses from the self-assessment document are reported in Table 5 and Table 6. As discussed in previous sections, there are both strengths and limitations in the collection and analysis of these data. It is recommended that future studies at this site address these concerns, especially the inclusion of a measure of uncertainty. The reported losses should not be treated as exact; any use of these values should come with the stipulation that there are multiple sources of uncertainty that may change the values if more information becomes available.

Table 5. Flow-corrected number of impinged fish and results from the equivalent age model (EAM), production foregone model, and equivalent yield model (EYM) from the impingement sampling at the Point Lepreau Generating Station between October 2013 and August 2014. Modified from the self-assessment document (EcoMetrix 2017). Dashes indicate the model was not used for that species. Production foregone was calculated for forage species only and equivalent yield was calculated for commercial, recreational and Aboriginal fishery species only.

Species	Number of Fish impinged	Age-1 equivalents	Production Foregone (kg)	Equivalent yield (kg)
Atlantic Cod	160	174	-	41
Atlantic Herring	27,708	29,602	-	2,070
Blackspotted Stickleback	1,115	1,102	0.5	-
American Lobster	2	3	-	1

Species	Number of Fish impinged	Age-1 equivalents	Production Foregone (kg)	Equivalent yield (kg)
Northern Shrimp	6,206	5,773	-	18
Rainbow Smelt	569	779	10.7	-
Red Hake	1,945	1,840	-	345
Rock Crab	479	93,288	-	27
Rock Gunnel	43	154	0.4	-
Shorthorn Sculpin	629	1,100	-	24
Winter Flounder	2,055	2,558	-	170

Table 6. Flow-corrected losses and results from the equivalent age model (EAM), production foregone model, and equivalent yield model (EYM) from the entrainment sampling at the Point Lepreau Generating Station between October 2014 and October 2015. Modified from the self-assessment document (EcoMetrix 2017). Dashes indicated the age class (eggs versus larvae) was not collected or the model was not used for that species.

Species	Flow-corrected number of eggs	Flow-corrected number of larvae	Age-1 equivalents (eggs and larvae)	Production Foregone (kg)	Equivalent yield (kg)
American Plaice	5,242,871	-	103	-	10
Atlantic Cod	-	443,904	1,041	-	206
Atlantic Herring	-	1,281,942	3,639	-	276
Fourbeard Rockling	268,139,591	225,841	281,445	8,990	-
American Lobster	-	427,119	3,441	-	739
Northern Shrimp	-	231,505,075	12,999,625	-	41,386
Red Hake	20,639,392	-	38,452	-	7,281
Rock Crab	-	333,596,420	25,332,057	-	2,689
Rock Gunnel	-	7,259,390	928,090	10,437	-
Silver Hake	20,512,173	-	108	-	8
Windowpane	17,559,873	-	322	-	3
Winter Flounder	-	580,797	35,553	-	2,939

Background Information Relevant to Discussing Impacts

Quantifying the response of a population to a stressor is complex and can require detailed information on many components of population dynamics (i.e., growth, mortality, movement). This level of detail in available data is often lacking or it is not reasonable to conduct assessments for every species and stressor. When discussing the impacts of losses due to the PLNGS on the species surrounding Point Lepreau and the corresponding offsetting measures, information on population characteristics, timing of mortality, and cumulative effects can be helpful. When species- or population-specific information is sparse or unavailable, consideration of these three categories and how they relate to each other, along with a basic understanding of population dynamics, can allow for a qualitative assessment of the potential impact.

Population Characteristics

Although two species may lose the same number of animals, the impact to the population will depend on multiple factors. The size and status of a population, life history characteristics, and the proportion of the population encountering the source of the morality all contribute to the population level impact. For example, the impact to an abundant r-selected species (i.e., species that have a high reproductive rate and a comparable short life-span) with a large geographic extent, such as Atlantic Herring, is expected to be low even with a large number of reported losses (relative to other species). In contrast, even with a very low mortality rate the impact to a population such as the inner BoF Designatable Unit of Atlantic Salmon, would likely be high due to the population size (low; DFO 2020) and population status (endangered; COSEWIC 2010). Other density-dependent processes of population dynamics will also be affected by the size and status of the population.

Additionally, when discussing the potential for population impacts it is important to differentiate between a reduction in the total population versus a localized depletion. It is possible that a high mortality rate may result in a localized depletion with negligible effects on the overall population size. This would be expected of species that have a wide geographic range with a single well-mixed population.

Timing of Mortality

Population-level impacts depend on the life stage that is affected, especially if there is the potential for compensatory effects (Rose et al. 2001). Fish generally become more reproductively valuable to a population as they age, so the loss of a juvenile is not equivalent to the loss of a spawning adult. Additionally, the duration and pattern in a mortality “event” affects the population-level impact. The two extremes of this spectrum are chronic, continuous mortality and short, discrete, episodic events (e.g., Callaway et al. 2013).

For example, spawning adults that are constantly subjected to a high mortality rate may contribute to an elevated total mortality rate for the population, thereby reducing the number of recruits and population growth rate. This would likely result in a marked population decline. Conversely, a single, episodic mortality event affecting only eggs may be balanced by compensatory effects (Rose et al. 2002) if the remaining eggs now have an increased chance of survival due to a reduction in competition for resources.

Cumulative Effects

Increased stress on a population generally decreases productivity and overall population size. There may be multiple sources of a single stressor, such as direct mortality, that can act cumulatively. For example, the impingement or entrainment losses at the PLNGS is an additional source of direct mortality (natural, fishing, other anthropogenic sources, etc.). There may also be other stressors experienced by a population that reduce productivity, such as access to habitat, nutrient availability, temperature and food supply (DFO 2014). Stressors may be additive (i.e., they are independent) or multiplicative and the effect on productivity may be greater than simply combining individual impacts. When discussing the impact of impingement and entrainment losses on a population, consideration of cumulative effects due to other stressors on the population should be included.

Will the Reported Annual Mortality Have an Effect on the Localized Population Levels

For the majority of the species impinged and entrained at the PLNGS, it is likely that only a small proportion of the overall population is encountering the facility. For species with a large geographic extent and healthy population status, even the extreme case, where 100% of individuals in the area are impinged or entrained, is unlikely to result in a local depletion due to the maintenance of a source that would not encounter the facility. As previously discussed, the population characteristics, timing of mortality, and potential for cumulative effects should also be considered when discussing impacts for specific species and populations. Using the reported losses from the document, examples of moderate and low impact potentials are described below. Although none were recorded, Atlantic Salmon is used as an example for a high impact species. There are multiple sources of uncertainty in the calculation of the reported losses and although they are the basis for moving forwards, the reported losses should not be considered infallible. For the majority of species, the reported losses are relatively low and would likely result in a low population-level impact.

- ***High impact potential***: impingement of adult Atlantic Salmon

The Inner BoF, Outer BoF, and Southern Uplands designatable units (DU) of Atlantic Salmon are considered endangered by COSEWIC (COSEWIC 2010), while the Inner BoF DU is also a SARA-listed species. It is possible for migrating adults from any of these units to encounter the PLNGS. Due to the very low population size, high value of spawning adults, constant potential for impingement mortality, and the additional stressors already experienced by the species, any additional direct mortality from the PLNGS is expected to have a large impact on the population.

- ***Moderate impact potential***: entrainment of Northern Shrimp larvae

Northern Shrimp have a discontinuous circumpolar distribution with part of their range extending along the eastern coast of North America as far south as Massachusetts, USA (Shumway et al. 1985). Northern Shrimp in the BoF fall within Shrimp Fish Area (SFA) 16 but it is unclear if they are a part of the Gulf of Maine (GoM) stock, the eastern Scotian Shelf (ESS) stock or another distinct population. The GoM stock has been under a fishing moratorium since 2014 and as of 2018, there is still a high likelihood that the stock is at a low level of abundance (ASMFC 2018). Additionally, recruitment is estimated to be low and ASMFC (2018) recommends exploring if climate change, increased predation, or other ecosystem factors may be contributing to the low productivity of the stock. The ESS stock is considered to be in the healthy zone and there is no active fishery in SFA 16 (DFO 2021a).

The reported mortality at the PLNGS was estimated at over 200 million larvae entrained annually. Although only a small portion of the GoM stock is expected to encounter the PLNGS, the impact of the reported mortality at the PLNGS may be moderate if the larvae originate from the GoM stock due to the low stock status and concerns about low recruitment and productivity. If the larval shrimp identified in the study are from the ESS stock, the impacts may be less given the robust population estimates (DFO 2021a).

- ***Low impact potential:*** impingement of American Lobster

American Lobster are found throughout the BoF and are fished commercially around the PLNGS in Lobster Fishing Area (LFA) 36. The stock in LFA 36 is considered to be in the healthy zone with a high sustained catch per unit effort since 2013; above the upper stock reference. Recruitment is estimated to be high and commercial landings reached record levels in 2018 (DFO 2021b).

The reported annual losses at the PLNGS were estimated to be less than 500,000 entrained larvae. Given the low reported losses, combined with a healthy population size and increasing recruitment, impacts to American Lobster populations due to the PLNGS are likely low.

Will the Reported Annual Mortality Result in Losses in Future Productivity?

When an individual fish is removed from a population through direct mortality, its future reproductive potential is lost. The loss of a fish from a population affects the population dynamics and can affect future productivity of the stock. Generally, as a stressor increases, productivity of a fish population decreases, but this relationship may be modified based on the potential for density-dependent effects (DFO 2014). For example, a Beverton-Holt curve models the relationship between the number of spawners and number of recruits (Figure 1). A change in the number of spawners will result in a change in the number of recruits, but the rate of change is dependent on the starting number of spawners even when the absolute loss of spawners is equivalent. In Figure 1, a reduction from 15 spawners to 5 results in a reduction of 22.5 recruits (A), while a reduction from 80 to 70 spawners results in a reduction of less than one recruit (B).

The continuous nature of the impingement and entrainment losses at the PLNGS may result in a reduction of a species' productivity to a lower level than it would be in the absence of effects from the PLNGS. This reduction would scale with the degree of impingement and entrainment losses experienced by the population. Loss of productivity is not discussed in the self-assessment document but may warrant consideration in future studies, especially if there are any changes to the impingement or entrainment rates, life stages being affected, or the population status of the species identified in the study. Although it is possible for the current reported losses of any species at the PLNGS to result in the loss of future productivity, the reported losses are generally low, as well as occurring on very early life stages, and the overall impact would likely be low for the majority of species.

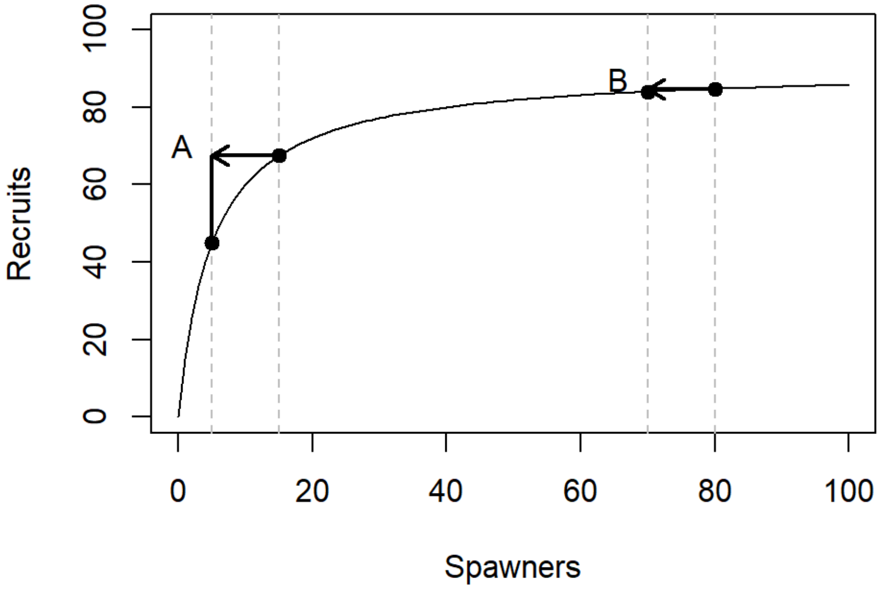

Figure 1. Beverton-Holt stock recruitment curve for a hypothetical population. Vertical dashed lines represent a reduction of 10 spawners at two different starting spawner abundances to illustrate the difference in the corresponding decrease in recruits.

The Report Gives Mortality Rates, Can this be Extrapolated to Indicate an Impact on CRA Fisheries?

As part of the self-assessment document, commercial landings from the Maritimes Region and equivalent yield loss in dollar amount were presented as a comparison to the reported losses at the PLNGS. The equivalent yield loss provides context but is not equivalent to the loss of that dollar amount from the fishery directly. Several assumptions are necessary to compare the reported losses at the PLNGS to the commercial value. First, it is assumed that the early life stages encountering the PLNGS are from the same population(s) that contribute to the commercial landings. Second, the loss of early life stages at the PLNGS will result in either a direct or indirect population-level impact. Finally, the fishery control measures (either catch quotas or effort) are sensitive to the changes in the population due to losses at the PLNGS.

Significance of the Reported Mortality Conclusions

When discussing the 'significance' of the reported mortality on the species surrounding Point Lepreau and corresponding offsetting measures, information on population characteristics, timing of mortality and cumulative effects can be helpful in the decision-making process. Even when species- or population-specific information is sparse or unavailable, consideration of these three categories and how they relate to each other, along with an understanding of population dynamics, can allow for a qualitative assessment of the potential impact. For the majority of the species impinged and entrained at the PLNGS, the population-level impacts and losses to future productivity are likely low. There are a few exceptions, such as Northern Shrimp, due to the low population size and status of the Gulf of Maine population. The conclusion of low population impact for most species is based on the reported losses from the self-assessment document. As discussed in previous sections, there are both strengths and limitations in the collection and analysis of these data and future studies at this site would benefit from a study design that incorporates a measure of uncertainty. The reported losses and their corresponding impacts may change if more information becomes available, or there are any changes to the population size, status or exposure to other stressors.

What are the Possible Mitigation and Offsetting Methods that Could be Implemented to Reduce the Impacts Associated with the Operations of the PLNGS?

Once the impacts associated with the PLNGS have been adequately identified and quantified it is necessary to discuss possible mitigation and offsetting measures. At the time of publication of this report, offsetting measures were already agreed upon and the options outlined in Ecometrix (2017) were not discussed herein.

Measures Already in Place at the Point Lepreau Generating Station

The authors describe three mitigation measures suggested by the United States Environmental Protection Agency (USEPA 2014) that are already in place for the PLNGS. First, the CW intake structure is placed offshore (approximately 700 m), and is designed to deter organisms from easily accessing the intake structure. These design elements include: a submerged velocity cap that alters flow conditions, allowing fish to more easily detect and avoid the structure; and a modified bottom with a 2.5 m riser and lip to prevent benthic organisms from easily crawling into the intake structure. These design elements are considered best practice by ECCC (formerly Environment Canada 1985) and the USEPA (2014). Second, flow velocities are considered low (0.27 m/s) relative to the burst swimming capabilities of dominant fish species in the area. This flow velocity at the edge of the intake is approximately double the recommended “best technology available” velocity of 0.15 m/s (USEPA 2014). Additionally, the intake system was designed to accommodate two generating plants, with an intake flow of 0.47 m/s when two units are operating. Therefore, if a second unit is ever installed, the intake velocity would be greater than the reported swimming speeds of many resident fish species. Finally, necessary power plant maintenance shutdowns are scheduled when significant abundances of organisms are known to occur in the area surrounding Point Lepreau. Multi-year, site-specific abundance data are non-existent for the PLNGS; therefore, there is no reliable means to predict abundance patterns of species of concern to schedule planned outages. Once seasonal patterns in abundance are characterized, planned outages scheduled to occur contemporaneously with times of high animal abundance or spawning events could potentially reduce large impingement or entrainment events.

Options for Further Mitigation

The authors proposed two additional design considerations that could help mitigate fish impingement: coarse intake screens and construction of a fish return system (FRS). These design changes would be added to the existing structures. The proposed design changes may help reduce impingement of larger species but will not reduce entrainment of eggs or larvae.

The coarse intake screen, which would be installed at the existing CW intake, is a design feature recommended by the USEPA as a means to reduce impingement of larger organisms (USEPA 2011). Depending on the size of the mesh, this would stop species like seals from making their way into the CW system. The coarse intake screen may also reduce the edge velocity of the water being drawn into the CW system, with the potential to reduce the impingement and entrainment of slow swimming species. As noted by the authors, biofouling and intake blockages may become an issue that could compromise the effectiveness of the cooling system and therefore nuclear reactor safety. Due to the location of the CW intake, regular maintenance would be challenging. The authors suggested a cost-benefit analysis including maintenance costs and safety concerns of the installation of a coarse screen would need to be conducted before moving forward with any modifications.

The second design option proposed by the authors to mitigate mortality related to fish impingement was the construction of an FRS. An FRS would allow for fish and other organisms impinged on the travelling screens of the CW system to be removed alive and returned to the ocean. The self-assessment report provided a summary of design considerations, such as flow dynamics, necessary for an effective FRS (EcoMetrix 2017; Table 10.1) which were modified from EPRI (2015). According to the authors of the self-assessment document and the engineering design report of the cooling system at PLNGS (Albery, Pullerits, Dickson, and Associates 1982), many of the components needed for an FRS are already in place. For example, the automated screen washing system, which periodically lifts and washes debris from the travelling screens, could be adapted to be part of an FRS. Organisms can suffer traumatic and often fatal injuries when impinged even for a short period of time and therefore adaptations to the existing system should take this into account.

Mitigation and Offsetting Conclusions

The PLNGS currently uses several mitigation measures to limit the impingement and entrainment of fish and invertebrates. The shape and placement of the CW intake is considered to be best practice according to USEPA (2014) but improvements could be made to the intake velocities at the station to further reduce impingement and entrainment. Planned outages during times of high larval/egg density for species of concern is also considered although more data would be required to make evidence-based decisions on when and how long these outages should occur. Improvements to the existing structure, such as a coarse intake screen and fish return system may further reduce impingement of large fish and mammals, although biofouling may present a safety concern if the cooling water is unable to effectively cool the nuclear reactors. Habitat restoration projects, such as planting eel grass beds, are a reasonable option for offsetting the losses due to the operation of the PLNGS. A targeted approach to improve the habitat of the species most affected by the PLNGS would provide the most direct benefit and may warrant consideration.

Conclusions

The operation of the PLNGS results in the death of fish primarily through the entrainment of eggs and larvae. For the majority of species, the reported losses at the PLNGS from the self-assessment document would likely result in a low population-level impact and low impact to future productivity. A low level of impact is driven by the relatively low reported losses and corresponding equivalent yields. The species with the largest reported loss and a potentially moderate population impact was Northern Shrimp. Approximately 232 million larvae, an equivalent fisheries yield of 41 mt, were estimated to be lost annually. Although the population of origin is unknown, a likely candidate is the stock from the Gulf of Maine, which is currently under a fishing moratorium due to low stock status and low recruitment.

While the field methods and analyses followed best practices for estimating losses due to impingement and entrainment, there are several areas of concern that introduce an element of uncertainty in the final reported losses. First, entrainment sampling may not have been representative of the species or densities available in the forebay. The number and timing of samples was limited, the forebay was assumed to be well mixed, and there was no repeatability in the sampling design. Second, errors in the raw data processing, such as misidentification of larval versus juvenile life stages, has the potential to underestimate survival to age-1. Considering many species were estimated to have millions of larvae entrained, the true value could be over- or under-reported by orders of magnitude. Third, there are major concerns with the extrapolation from raw data to the flow-corrected annual losses presented in the document due to the low sample volume, low sample frequency, zero-inflation in the data and lack of numerical uncertainty in the results. For example, 9 of 120 entrainment samples contained a single Atlantic Herring larva. These nine larvae were flow-corrected to a total loss of over 1.2 million larvae. Finally, the three models used in the study treated all life-history parameters as known and fixed.

Future studies to address impingement and entrainment at the PLNGS would benefit from a study design that includes random sampling with temporal stratification, which would address many of the concerns surrounding the lack of uncertainty and issues with sample size and timing. The assumption that the forebay is well mixed and entrained organisms are uniformly distributed throughout, should be investigated with a separate study. The inclusion of a fourth model to evaluate the lost reproductive potential of impinged or entrained individuals would be beneficial in closing the lifecycle when evaluating losses at the PLNGS. Finally, all models would benefit from the inclusion of a measure of numerical uncertainty in the life history parameters instead of treating them as known and fixed. Due to the issues identified in this review, the reported losses and their corresponding impacts may change if more information becomes available, or if there are changes in the size and status of the affected populations.

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