The English Bay Lakes Salmon Enhancement Project was made possible through enhancement taxes paid by the commercial fishermen in Area H, Cook Inlet and associated waters, through the harvest and sale of surplus fish and through an Alaska Sustainable Salmon Fund grant received from the Alaska Department of Fish and Game (Project Number 44717).
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DISCLAIMER

The Cook Inlet Aquaculture Association (CIAA) conducts salmon enhancement and restoration projects in Area H, Cook Inlet and associated waters. As an integral part of these projects a variety of monitoring and evaluation studies are conducted. The following final report is a synopsis of the monitoring and evaluation studies conducted for the English Bay Lake salmon enhancement project between 2013 and 2015. The purpose of this report is to provide a vehicle to distribute the information produced by the monitoring and evaluation studies.

CIAA maintains a strong policy of equal employment opportunity for all employees and applicants for employment. We hire, train, promote, and compensate employees without regard for race, color, religion, sex, sexual orientation, national origin, age, marital status, disability or citizenship, as well as other classifications protected by applicable federal, state or local laws.

Our equal employment opportunity philosophy applies to all aspects of employment with CIAA including recruiting, hiring, training, transfer, promotion, job benefits, pay, dismissal and educational assistance.
ACKNOWLEDGEMENTS

The English Bay Lakes smolt and adult enumeration project was conducted by the Cook Inlet Aquaculture Association in cooperation with the Nanwalek Village Council. Appreciation is extended to all the full-time and seasonal staff who participated in this project between 2013 and 2015. Appreciation is also extended to the Nanwalek Village Council, Chugachmuit, and the Alaska Department of Fish and Game for their support.
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Table 11. Brood year contributions to adult migration in each year. Purple highlights indicate the completed brood year covered by this study.
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ABSTRACT

Sockeye salmon population enhancement projects have been completed in the English Bay Lakes system for a number of years. Currently, each fall approximately 200,000 sockeye salmon fry (Oncorhynchus nerka) averaging 2.4–2.6 gm in size are stocked into Second Lake. To determine the success of this stocking program and to provide migration numbers to the Alaska Department of Fish and Game for fishery management, Cook Inlet Aquaculture Association (CIAA) conducted a 3-year study (2013–2015) under an Alaska Sustainable Salmon Fund grant to enumerate and provide population characteristics (age, length, weight and hatchery contribution) for the smolt migration and adult escapement of sockeye salmon in the English Bay Lakes system.

Between 2013 and 2015, the number of smolt migrating from the system was fairly consistent ranging between 113,900 to 140,000. Age-1 was the predominant age class for the smolt migration (75%). The percentage of hatchery-origin smolt migrating each year was variable with a high of 41.3% in 2013 to a low of 14.2% in 2015. For completed brood years, the survival from stocking to smolt ranged from 14.5% to 19.5%. This survival rate is lower than expected for a fall fry stocking program. There were no size differences between hatchery-origin and naturally-produced smolts but it was noted that hatchery-origin fish predominantly migrated with a higher rate of age-1 smolt than their naturally-produced counterparts, which had a higher number of age-2 smolts.

Adult sockeye salmon escapement to the system were variable ranging from 6,290 in 2015 to a high of 12,657 in 2013. The predominant year class was age-4 (1.3 and 2.2) with nearly 70% of the return. Age-3 (1.2) and age-5 (2.3) equally contributed to the remaining 30%. Hatchery contribution to the adult escapement varied from a low of 7.0% in 2013 to 14.7% and 13.1% in 2014 and 2015 respectively. No conclusion can be made at this time as to any differences in marine survival between hatchery- and naturally-produced fish because only one brood year (BY09) had fully returned during the course of this study.
INTRODUCTION AND PURPOSE

English Bay Lakes is located on Alaska's Kenai Peninsula near the community of Nanwalek, Alaska. The English Bay Lakes system is a chain of five small lakes with a total surface area of approximately 200 hectares. The sockeye salmon (*Oncorhynchus nerka*) that return to this system are a vital resource to the subsistence culture of the Port Graham and Nanwalek villages. In the 1980s, a downward trend in harvests and escapement led to a number of evaluations to determine the reasons for the decline and possible solutions.

One such solution was the stocking of sockeye salmon fry or pre-smolts in order to provide a greater return of adults and fishing opportunities. This sockeye salmon enhancement project has been operating for over 20 years and has been modified several times. Stocking was originally performed by the Alaska Department of Fish and Game (ADF&G), but was taken over by the Chugach Regional Resources Commission in cooperation with the Native Village of Nanwalek and the Bureau of Indian Affairs as the Nanwalek Salmon Enhancement Project. Management of the stocking program was eventually transferred to the Port Graham Hatchery but when the hatchery closed down, Cook Inlet Aquaculture Association (CIAA) took over the stocking program. Table 1 provides a summary of the stocking effort since 1989.

Concurrently, with the start of the stocking program, ADF&G conducted a study to determine the rearing capacity and potential for sockeye salmon enhancement in English Bay Lakes. This study (Edmundson et al., 1992) concluded that because of a high flushing rate, the amount of sockeye salmon that could be reared in the system was limited by the food resource. This study concluded that by balancing juvenile production with the forage base, a sustainable level of smolt production and adult return could be achieved. It was recommended that a pre-smolt stocking program be considered to minimize the impact on the zooplankton community. Additionally, the study recommended a sampling project to determine the population characteristics of the migrating smolts as well as continued limnology and zooplankton sampling.
### Table 1. Stocking performed at English Bay Lakes (1989–2015).

<table>
<thead>
<tr>
<th>Agency</th>
<th>Hatchery</th>
<th>Brood Year</th>
<th>Stock</th>
<th>Species</th>
<th>Stage</th>
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</table>

*Note: PGHC = Port Graham Hatchery Corporation*
Historically, the Nanwalek Salmon Enhancement Project operated a trap to enumerate sockeye salmon smolt leaving the lake system and a weir to enumerate adult sockeye salmon returning. The resulting numbers were used to forecast the expected return and to calculate escapement to the English Bay Lakes in order to manage the subsistence and commercial harvests. However, data gaps created by the lack of consistent funding and the resultant sporadic enumeration of sockeye salmon smolt and adults have not made this an easy task.

Starting in 2012, CIAA took over the operation to enumerate and characterize the smolt and adult migrations. In 2013, CIAA was awarded an Alaska Sustainable Salmon Fund grant (AKSSF 44717) for funding the smolt and adult migration components. All hatchery activities (incubation, rearing, stocking, and gamete collection) were funded solely using CIAA monies.

The objectives of the AKSSF grant project were twofold. First, the project would provide data on the number and population characteristics of sockeye salmon emigrating and migrating to the English Bay Lakes system. Second, the data collected would also be used to compare the survival and population characteristics of the naturally produced sockeye to those stocked by the hatchery.
PROJECT AREA

English Bay Lakes is located on Alaska's Kenai Peninsula near the community of Nanwalek, Alaska (Figure 1). It is a system comprised of a chain of five small lakes with a total surface area of approximately 200 hectares. Second and Third lakes are the two primary salmon producers.

Figure 1. General location of English Bay Lakes system.
Second Lake has a surface area of $0.70 \times 10^6$ m$^2$ (150 acres), a mean lake depth of 10.9 m, a maximum depth of 25.9 m, and a total volume of $7.6 \times 10^6$ m$^3$ (Figure 2). Third Lake, drains into Second Lake, has a surface area of $0.72 \times 10^6$ m$^2$ (166 acres), a mean lake depth of 14.7 m, a maximum depth of 29 m, and a total volume of $10.6 \times 10^6$ m$^3$ (Figure 3). The hydraulic residence time is approximately 15 days for Second Lake and 35 days for Third Lake. Total annual outflow of Second Lake is more than 20 times greater than its volume and for Third Lake the outflow is nearly 10 times its volume (Edmundson et al., 1992).

Figure 2. Bathymetric overview of Second Lake.
Figure 3. Bathymetric overview of Third Lake.
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METHODS

For each year of the study, CIAA constructed two smolt traps, enumerated smolts migrating from the lake and lethally sub-sampled a portion of the population to determine the age, length, weight and hatchery contribution. Similarly, for the adults, a weir was constructed across English Bay River each year and adult salmon were enumerated. A sub-sample of the returning adult sockeye salmon population was lethally sampled to determine age, sex, length, weight and hatchery contribution. For both migrations, environmental conditions were recorded.

Additionally, while outside of the scope of the AKSSF grant, CIAA conducted annual stocking of fall fry each October to Second Lake and conducted egg takes each September (with the exception of 2015). Information for these two operations are not included in this completion report but can be found in the annual progress report prepared by CIAA (Cherry, 2013a; Cherry, 2013b; Cherry, 2015; Cherry, 2016).

A general description of the procedures followed is given below. Greater detail can be found in the yearly smolt and adult enumeration manuals (CIAA, 2013a; CIAA, 2013b; CIAA, 2014a; CIAA, 2014b; CIAA, 2015a; CIAA, 2015b).

Environmental Conditions

Daily observations completed at 5:00 P.M. throughout the summer field season included percent cloud cover, precipitation to the nearest millimeter, and stage height. Air and water temperature were recorded every four hours using a Hobo® data logger. All recordings in a 24-hour period were averaged to provide a daily average air and water temperature. Unfortunately, the Hobo® data logger stopped working on May 28, 2014 because of dead battery for the air temperature hence these data are incomplete.

Smolt Enumeration

To enumerate the smolt migration, two smolt traps were temporarily placed in English Bay River approximately 0.29 miles downstream of First Lake. Each smolt trap consisted of a modified net
with nylon mesh leads and a double compartment live box. Each trap connected to each other and covered the entire width of the river, so that all migrating smolts had to go through a trap (Figure 4).

For smolt enumeration, fish migrating downstream were directed by the net into a live box where they were captured, temporarily held, identified to species, counted and released downstream. Total counts of smolts migrating from the lake system were typically made until the migration of fish exceeded 2,000 to 3,000 fish per hour. When this occurred, a 10% sub-sampling procedure was available to enumerate the migrating smolts.

To enumerate migrating smolts with the 10% sub-sampling procedure, the counting period was divided into 20-minute intervals. During each 20-minute interval, migrating fish were directed into the live-box for two minutes and then counted. During the remaining 18 minutes, migrating smolts were passed through the traps uncounted. The two-minute smolt count was multiplied by 10 to estimate the number of smolts migrating during the twenty minute interval.

Figure 4. The English Bay Lakes smolt traps.
Assuming the two-minute sub-sampling intervals were randomly distributed throughout sub-sampling\(^1\) and smolt moved through the weir randomly, the total smolt migration was estimated as follows:

If:

\[ T_c = \text{number of fish counted with the total count procedure}, \]
\[ \hat{T}_s = \text{number of fish counted with the 10\% sub-sampling procedure}, \]
\[ \hat{T} = \text{the total smolt migration}, \]
\[ y = \text{the number of fish counted in each two minute sub-sampling interval}, \]
\[ n = \text{the number of two minute sub-sampling intervals sampled}, \]
and
\[ N = \text{the number of possible two minute sub-sampling intervals}, \]

Then:

\[ \hat{T} = T_c + \hat{T}_s \]

and the variance is,

\[ v(\hat{T}_s) = N^2((N-n)/N)\sum(y_i - \bar{y})^2 / (n(n-1)) \]

And:

\[ C.I._{\alpha=95\%} \text{ for } \hat{T}_s = \pm 2\sqrt{v(\hat{T}_s)} \]

The variance about the estimated smolt migration, \( \hat{T} \), is equal to the variance about \( \hat{T}_s \), because \( T_c \) is a total count with 0 variance.

For all three years of the study, no 10\% sub-sampling procedure was required. Enumerations were performed daily for the entire smolt migration with the exception of 2014 where a flood event in early June blew out the trap and no data were collected for a three day period. Generally, smolt migration began in early May and was completed in early July. The smolt migration in 2015 was an exception to this trend, when enumeration began in late April due to

\(^1\) Predetermined randomly selected 2-minute sub-sampling intervals assured random distribution within each 20-minute period.
warm spring conditions.

**Smolt Characteristics and Enhanced Contribution**

To evaluate the success of the enhancement project, staff collected a sample of sockeye salmon smolt migrating to determine age, weight, and length characteristics of the population as well as the number of hatchery- and naturally-produced smolt. All fish released by CIAA were thermally marked.\(^2\)

The smolt collected for measurement, age determination, and otolith removal were sampled in proportion to the daily smolt migration. This was accomplished by collecting every 200\(^{th}\) sockeye smolt that passed through the smolt trap. The numbering sequence began when the first fish passed through the trap and continued consecutively until the smolt migration was complete.

Each smolt collected for evaluation was first measured to the nearest millimeter for fork length\(^3\) and weighed to the nearest 0.1 gram. Otoliths were removed and placed in a labeled one dram vial filled with a 10% ethanol solution. Each otolith was checked for a hatchery mark following procedures described by Glick and Shields (1993). Otoliths were also used for aging.

Sockeye smolt characteristics, the proportion of enhanced sockeye smolt and the proportion of age-1 and age-2 sockeye smolt in the migrating population, were estimated with the following notations and formulas provided by ADF&G.

If:

- \( N \) = total number of migrating smolts,
- \( N_h \) = number of smolts in stratum \( h \), \( (N = \sum N_h) \),
- \( n \) = total number of smolts sampled,
- \( n_h \) = number of smolts sampled in stratum \( h \), \( (n = \sum n_h) \),
- \( a \) = total number of enhanced smolts sampled,

---

\(^2\) The otolith mark is a hatchery induced thermal band produced by controlled temperature changes during incubation.

\(^3\) Standard fork length was measured from the tip of the snout to the fork of the tail.
\[ a_h = \text{number of enhanced smolts sampled in stratum h}, \quad (a = \sum a_h), \]
\[ p_h = a_h / n_h, \quad \text{The proportion of enhanced smolts in stratum h}, \]
\[ q_h = 1 - p_h, \quad \text{The proportion of wild smolts in stratum h}, \]
\[ c_i = \text{number of age=}\, i\, \text{smolts sampled}, \]
\[ c_{hi} = \text{number of age=}\, i\, \text{smolts sampled in stratum h}, \quad (c_i = \sum c_{hi}), \]
\[ l_{hi} = c_{hi} / n_{hi}, \quad \text{The proportion of age=}\, i\, \text{smolts in stratum h}, \]
\[ m_{hi} = 1 - l_{hi}, \quad \text{The proportion of other than age=}\, i\, \text{smolts in stratum h}, \]
\[ f = n / N, \quad \text{The sampling fraction (assumed equal in all strata)}, \]
\[ W_h = N_h / N, \quad \text{The stratum weight}, \quad \text{and,} \]
\[ y = \text{the weight or length of the smolt}. \]

Then the proportion of enhanced smolts, \( \hat{P} \), was estimated as:
\[ \hat{P} = a / n; \quad \text{with a variance of} \quad v(\hat{P}) = (1 - f)(1 / n)\sum W_h p_h q_h; \]
which, under proportional allocation, is like the usual simple random sample estimate.

The total number of enhanced smolts, \( \hat{A} \), was also estimated as:
\[ \hat{A} = N(a / n) = N\hat{P}; \]
with a variance of:
\[ v(\hat{A}) = N^2(1 - f)(1 / n)\sum W_h p_h q_h = N^2 v(\hat{P}). \]

Since samples sizes were fairly large and \( \hat{P} \) was not extreme, the normal approximation, without a correction for continuity, could be used to develop the relative error. Thus, the 95\% confidence interval estimate for \( \hat{P} \) and \( \hat{A} \) is:
\[ \hat{P} \pm 1.96\sqrt{v(\hat{P})} \quad \text{and} \quad \hat{A} \pm 1.96\sqrt{v(\hat{A})}; \]
and, the relative error is:
\[ R.E. = \left( 1.96\sqrt{v(\hat{P})}/(\hat{P}) \right) 100 \quad \text{and} \quad R.E. = \left( 1.96\sqrt{v(\hat{A})}/(\hat{A}) \right) 100. \]

The proportion of age=\, i\, smolt in the smolt migration was also estimated as:
\[ \hat{L}_i = c_i / n; \quad \text{with a variance of} \quad v(\hat{L}_i) = (1 - f)\frac{1}{n} \sum W_h l_{hi} m_{hi}; \]
and, the total number of age=\, i\, smolts was estimated as:
\[ \hat{C}_i = N(\hat{L}_i); \] with a variance of \[ v(\hat{C}_i) = N^2 v(\hat{L}_i). \]

Confidence interval (95\%) estimates for age-class proportion and abundance, assuming 2 age-classes, are:

\[ \hat{L}_i \pm 2.24 \left( \sqrt{v(\hat{L}_i)} \right) \quad \text{and} \quad \hat{C}_i \pm 2.24 \left( \sqrt{v(\hat{C}_i)} \right). \]

Mean weight or length of age = \( i \) smolt was also estimated as:

\[ \bar{y}_i = \frac{\sum_h \sum_j y_{hij}}{c_i}; \]

with an approximate variance estimate of:

\[ v(\bar{y}_i) \approx \frac{1}{c_i^2} \sum_h \frac{N_i^2 (1 - f)}{n_h (n_h - 1)} \left[ \sum_j (y_{hij} - \bar{y}_{hi})^2 + c_h (1 - c_h/n_h)(\bar{y}_{hi} - \bar{y}_i)^2 \right]. \]

The confidence interval (95\%) estimate for the mean weight and length is:

\[ \bar{y}_i \pm 1.96 \left( \sqrt{v(\bar{y}_i)} \right). \]

**Adult Escapement**

To enumerate and collect adult sockeye salmon escaping to the English Bay Lakes, a counting weir was temporarily installed. The weir was constructed of 1.9 cm galvanized pipe and 7.6 cm aluminum channel spaced 2.54 cm apart (Figure 5).

Field personnel visually identified by species and counted the adult fish as they ascended English Bay River. By removing one or two pickets, fish were permitted to pass through the weir. Initially counts were made at least twice a day. As the number of adult fish passing through the weir increased, counts were made more frequently. In addition to the enumeration of the adult sockeye salmon escapement, the sex, age, and standard fork length of the returning population was also assessed by collecting a sample in proportion to the daily migration. This was accomplished by collecting every 50\(^{th}\) adult sockeye salmon that passed through the weir. The numbering sequence began when the first fish passed through the weir and continued consecutively until the adult migration was complete. The sex of each adult sockeye salmon was visually determined and the standard fork length measured to the nearest millimeter. For age and
hatchery contribution, field personnel removed the otoliths and placed them into labeled one dram vials filled with 10% ethanol solution. Each otolith was checked for a hatchery mark and aged following procedures described by Glick and Shields (1993). All adult sockeye salmon sacrificed for otolith collection were donated to the Nanwalek Village.

Figure 5. The English Bay Lakes adult weir, located in the background. 
*The return of adult sockeye overlap with the migration of the sockeye salmon smolt from the lake system.*
The proportion of enhanced adult sockeye was estimated using the following notations and formulae.

If:

\[ N = \text{total number of migrating adults}, \]
\[ n = \text{total number of migrating adults sampled}, \]
\[ a = \text{total number of enhanced migrating adults}, \]
\[ p = \text{the proportion of enhanced migrating adults}. \]

Then the proportion of enhanced adults, \( \hat{P} \), was estimated as:

\[ \hat{P} = \frac{a}{n}; \text{ with a variance of } \nu(\hat{P}) = \frac{(a/n)(1-a/n)}{n-1} \]

The total number of enhanced adults, \( \hat{A} \), was also estimated as:

\[ \hat{A} = N(\frac{a}{n}) = N\hat{P}; \text{ with a variance of } \nu(\hat{A}) = \nu(\hat{P})N^2. \]

Thus the 95% confidence interval estimate for

\[ \hat{A} = 1.96\sqrt{\nu(\hat{A})} \]
RESULTS AND DISCUSSION

The results reported here are a summary of the monitoring which took place between 2013 and 2015. Greater detail for each year and the raw data can be found in the annual progress reports (Cherry, 2013b; Cherry, 2015; Cherry, 2016).

Environmental Conditions

The environmental data for the three years of the study (2013–2015) are summarized in Table 2. In 2014, between 08 May and 31 July, the average air temperature could not be calculated due to a dead battery in the Hobo® data logger. Despite having significantly less precipitation in 2013 (90 mm versus 271 mm in 2015), the water temperatures were cooler than that experienced in 2014 and 2015.

Table 2. Environmental conditions observed at English Bay Lakes (2013–2015).

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Days</th>
<th>Clear</th>
<th>&lt;50% Cloud Cover</th>
<th>&gt;50% Cloud Cover</th>
<th>Overcast</th>
<th>100%</th>
<th>Rain</th>
<th>Meas. Precip</th>
<th>Precip (mm)</th>
<th>Air Temp (°C)</th>
<th>Water Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>57</td>
<td>17</td>
<td>17</td>
<td>9</td>
<td>10</td>
<td>4</td>
<td>21</td>
<td></td>
<td>152</td>
<td>10.4 (3-20)</td>
<td>7.6 (2-12)</td>
</tr>
<tr>
<td>2013</td>
<td>79</td>
<td>32</td>
<td>9</td>
<td>11</td>
<td>18</td>
<td>8</td>
<td>22</td>
<td></td>
<td>90</td>
<td>9.9 (2-20)</td>
<td>10.4 (5-16)</td>
</tr>
<tr>
<td>2014</td>
<td>82</td>
<td>22</td>
<td>19</td>
<td>17</td>
<td>10</td>
<td>14</td>
<td>36</td>
<td></td>
<td>230.8</td>
<td>inc</td>
<td>inc</td>
</tr>
<tr>
<td>2015</td>
<td>89</td>
<td>20</td>
<td>15</td>
<td>16</td>
<td>14</td>
<td>16</td>
<td>49</td>
<td></td>
<td>270.52</td>
<td>10.6 (4-16)</td>
<td>12.4 (5-17)</td>
</tr>
</tbody>
</table>

Rain days are counted as days with measurable precipitation and 100% overcast is measured as those days indicated as 100% overcast with or without measurable precipitation. Inc= incomplete due to equipment failure with the Hobo® datalogger.

Smolt Enumeration

Generally, the enumeration of sockeye salmon smolt emigrating from the lake began in the first week of May and continued until the first week of July. The only exception was in 2015 where warmer spring conditions results in an earlier ice out and enumeration began in late April. Total smolt enumerated each year was fairly consistent (Figure 6). In 2013, a total of 113,900 smolts were counted. In 2014, approximately 127,100 smolts were counted; however, flood conditions blew out the smolt trap so no data were recorded during this 3-day event. In 2015, a total of 140,000 smolts were counted. Figure 7 demonstrates the daily cumulative smolt count for each year.
Figure 6. The number of sockeye salmon smolt emigrating from English Bay Lakes (2013–2015). Note the count for 2014 is an approximation as the trap was blown out in a flood event and data are missing. Figures have been rounded to the nearest 100 fish.

Figure 6. The daily cumulative sockeye salmon smolt migration from English Bay Lakes (2013–2015). Note the count for 2014 is an approximation as the traps were not operated during a three day flood event and data are missing. Figures have been rounded to the nearest 100 fish.
In 2013, Alaska experienced a long and protracted spring with ice-out not occurring until the later part of May. In 2015, the opposite was experienced. Ice-out occurred early due to warm spring conditions and little snow pack/cold conditions during the winter. These conditions influenced the start of the smolt migration. However, once the migration began, the trend was similar with the highest daily migration of smolt occurring early and tapering off by early to mid-June. In 2014, the smolt migration was tracking very similar to that in 2015, but with the flood event during the peak of the run, a number of smolt were probably not counted. The 2014 smolt migration, although counted at 127,000, is probably closer to that experienced in 2015 (140,000). The migration was completed by early July in each year.

**Smolt Characteristics - Age and Size**

Otolith samples were collected from every 200th sockeye salmon smolt that went through the trap (0.5%). Otoliths were analyzed to determine age and hatchery contribution. Additionally, length and weight were recorded for each fish sampled. Table 3 summarizes the results for the three years of the project.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number</th>
<th>Hatch. 95% CI</th>
<th>No. Wild</th>
<th>Age-1 95% CI</th>
<th>Age-2 95% CI</th>
<th>1.0 95% CI</th>
<th>2.0 95% CI</th>
<th>Avg Length (mm)</th>
<th>Avg Weight (gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>113,900</td>
<td>41.3 3.9 66,900</td>
<td>84,700 4,200</td>
<td>29,200 4,184</td>
<td>68 0.7 76 3.8</td>
<td>2.5 1.3 4.1 0.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>127,100</td>
<td>25.7 3.3 94,400</td>
<td>100,000 4,505</td>
<td>27,100 4,494</td>
<td>68 0.5 74 0.6</td>
<td>2.4 0.3 3.2 0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>140,000</td>
<td>14.2 2.4 120,100</td>
<td>104,000 4,649</td>
<td>36,000 4,662</td>
<td>65 0.6 72 1.0</td>
<td>2.3 0.1 3.1 0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg.</td>
<td>127,000</td>
<td>27.1 3.2 93,800</td>
<td>96,200 4,500</td>
<td>28,200 4,400</td>
<td>67 0.6 74 1.8</td>
<td>2.4 0.6 3.5 0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>381,000</td>
<td></td>
<td>288,700</td>
<td>92,300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average length rounded to nearest mm and average weight rounded to nearest 0.1 g. All other figures have been rounded to nearest 100 fish.

Age-1 smolt was the predominant age class in each year averaging 75.7% (±3.5%) over the three years of the study (Figure 8). The remaining 24.3% (±3.5%) were age-2. There were no age-0 or age-3 smolt in any year. Average weight and length was consistent between each year of the study with age-1 smolt averaging 67 mm (±0.6 mm) in length and 2.4 gm (±0.6 gm) in weight. Age-2 smolt averaged 74 mm (±1.8 mm) and 3.5 gm (±0.3 gm) respectively in length and weight.
Figure 7. Age class breakdown on English Bay Lakes sockeye salmon smolt (2013–2015).

These results are similar to that reported in 1992, where 63% were age-1 and 37% were age-2 (Schollenberger, 1992). Average length and weight for the different age classes recorded in 1992 was also similar to those recorded between 2013 and 2015. In 1992, average weight and length for age-1 smolts were reported as 2.9 gm and 68 mm respectively, while the age-2 smolts were 3.8 gm and 75 mm (Schollenberger, 1992).

Smolt Characteristics - Hatchery Contribution

On an annual basis, the hatchery contribution to the smolt migration was variable throughout the study period ranging from a low of 14.2% (±3.9%) in 2015 and a high of 41.3% (±2.4%) in 2013 (Figure 9).

Smolt migrating from the English Bay Lakes system each year were a mix of brood years (age-1 and age-2). Table 4 illustrates when each brood year would have contributed to the smolt
migration. Over the period that this study monitored (2013–2015), only two brood year classes are complete—BY11 and BY12. Based on the otolith analysis for age and hatchery contribution, the number of hatchery and natural origin smolts that migrated out of the lake for each brood year can be determined. This information is illustrated in Figure 10. On a brood year basis, hatchery-origin fish was 37.54% of the smolt migration for BY11 and 22.87% for BY12.

![Chart showing hatchery origin smolt percentage by year](image)

**Figure 8.** Percentage of migrating sockeye salmon smolt determined to be of hatchery origin by calendar year. (2013–2015).

**Table 4.** Brood year contributions to sockeye salmon smolt migration at English Bay Lakes.

<table>
<thead>
<tr>
<th>Brood Year (Egg)</th>
<th>Rearing (Fry)</th>
<th>Smolt Migration Year Age-1</th>
<th>Smolt Migration Year Age-2</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>2011</td>
<td>2012</td>
<td>2013</td>
<td>Incomplete</td>
</tr>
<tr>
<td>2011</td>
<td>2012</td>
<td>2013</td>
<td>2014</td>
<td>Complete</td>
</tr>
<tr>
<td>2012</td>
<td>2013</td>
<td>2014</td>
<td>2015</td>
<td>Complete</td>
</tr>
<tr>
<td>2013</td>
<td>2014</td>
<td>2015</td>
<td>2016</td>
<td>Incomplete</td>
</tr>
</tbody>
</table>

*Blue highlights are the years covered by this study.*
Figure 9. Hatchery and natural origin sockeye salmon smolt from English Bay Lakes, completed brood years only (2011 and 2012).

Figures are rounded to the nearest 100 fish. Hatchery stocking remained consistent at approximately 200,000 pre-smolt each fall.

Smolt - Hatchery and Wild Comparison

Using the data collected from the otolith sampling during the smolt migration, it is possible to determine if there are significant differences among the characteristics of age and weight between the hatchery and wild smolt production. For each year of the study, there were no reported significant differences between hatchery and wild smolt for average weight within similar age classes (P>0.05) (Table 5). This would indicate that no one group (hatchery or wild) has any advantage in terms of feeding opportunities. This is further supported by the fact that the smolt size during this study is similar to that reported in 1992 (Schollenberger, 1992).

However, in terms of age contribution, the hatchery-origin fish tended to have 88%–97% of the population migrate from the lake as age-1 while the natural production tended to have a smaller age-1 (58%–76%) and greater age-2 component (24%–41%) (Table 6). This age characteristic is
also similar to historical data where 63% were determined to be age-1 and 37% were age-2 (Schollenberger, 1992). Further analysis of adult returns are necessary to determine if this difference in age class contribution contributes in any manner (positively, negatively or neutral) to the marine survival. The collection of these data are outside the time period of this study.

Table 5. Average weight (gm) comparison between hatchery and wild sockeye salmon smolt production for each age class, English Bay Lakes (2013–2015).

<table>
<thead>
<tr>
<th>Year</th>
<th>Group</th>
<th>Age-1 Weight (gm)</th>
<th>SD</th>
<th>Age-2 Weight (gm)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>Hatchery</td>
<td>2.51</td>
<td>0.68</td>
<td>2.92</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>Wild</td>
<td>2.55</td>
<td>0.80</td>
<td>4.17</td>
<td>2.90</td>
</tr>
<tr>
<td>2014</td>
<td>Hatchery</td>
<td>2.34</td>
<td>0.73</td>
<td>3.48</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>Wild</td>
<td>2.33</td>
<td>0.86</td>
<td>3.18</td>
<td>1.07</td>
</tr>
<tr>
<td>2015</td>
<td>Hatchery</td>
<td>2.38</td>
<td>0.73</td>
<td>3.34</td>
<td>1.69</td>
</tr>
<tr>
<td></td>
<td>Wild</td>
<td>2.24</td>
<td>1.15</td>
<td>3.04</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Table 6. Age class contribution between hatchery and wild sockeye salmon smolt production for each year, English Bay Lakes (2013–2015).

<table>
<thead>
<tr>
<th>Year</th>
<th>Group</th>
<th># Age-1</th>
<th>%</th>
<th># Age-2</th>
<th>%</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>Hatchery</td>
<td>223</td>
<td>97.0%</td>
<td>7</td>
<td>3.0%</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td>Wild</td>
<td>191</td>
<td>58.4%</td>
<td>136</td>
<td>41.6%</td>
<td>327</td>
</tr>
<tr>
<td>2014</td>
<td>Hatchery</td>
<td>138</td>
<td>88.5%</td>
<td>18</td>
<td>11.5%</td>
<td>156</td>
</tr>
<tr>
<td></td>
<td>Wild</td>
<td>339</td>
<td>75.5%</td>
<td>110</td>
<td>24.5%</td>
<td>449</td>
</tr>
<tr>
<td>2015</td>
<td>Hatchery</td>
<td>90</td>
<td>94.7%</td>
<td>5</td>
<td>5.3%</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>Wild</td>
<td>407</td>
<td>70.8%</td>
<td>168</td>
<td>29.2%</td>
<td>575</td>
</tr>
</tbody>
</table>

Smolt - Survival

As noted in Table 4 above, the fall fry that were stocked in 2012 and 2013 (BY11 and BY12) have completed their migration to the ocean (both age-1 and age-2 components), therefore it is possible to calculate survival from stocking to smolt. Table 7 summarizes the number of fall fry stocked and the corresponding smolt migration. The 14%–20% survival from stocking-to-smolt migration is lower than what would be expected for a fall fry stocking program. The survivals documented here are similar to that experienced for spring fry stocking programs (Bear Lake where the 4-year average survival = 21.1%; Hidden Lake where the 4-year average survival = 16.7%) (Cherry, In prep; Wizik and Cherry, In prep).
However, what is striking about the data, is that there was no growth and further there was a reduction in size between stocking in the fall and the smolt migration in the spring (see Table 8). This emphasizes the conclusion by Edmundsen et al. (1992), that the sockeye salmon production at English Bay Lakes is food resource limited.

Table 7. Fry-to-smolt survival for hatchery stocked sockeye salmon at English Bay Lakes, completed brood years only, (2011–2012).

<table>
<thead>
<tr>
<th>Brood Year</th>
<th>Fish Stocked (#)</th>
<th>Size at Stocking (gm)</th>
<th>Smolts Migrated (#)</th>
<th>Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>213,000</td>
<td>2.8</td>
<td>41,700</td>
<td>19.6%</td>
</tr>
<tr>
<td>2012</td>
<td>211,000</td>
<td>2.7</td>
<td>31,100</td>
<td>14.7%</td>
</tr>
</tbody>
</table>

Table 8. Comparison of fish size (gm) at stocking and at smolt migration, English Bay Lakes, completed brood years only (2011–2012).

<table>
<thead>
<tr>
<th>Brood Year</th>
<th>Size at Stocking (gm)</th>
<th>Size at Migration (gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>2.8</td>
<td>2.38</td>
</tr>
<tr>
<td>2012</td>
<td>2.7</td>
<td>2.51</td>
</tr>
</tbody>
</table>

Adult Escapement

Adult sockeye salmon began arriving at the weir on 23 May and continued to migrate until 31 July each year with the exception of 2013 where the first adult was not documented until 27 May. The highest adult escapement occurred in 2013 with 12,657 sockeye salmon counted. In 2014 and 2015, the adult sockeye salmon escapement decreased to 7,832 and 6,290 respectively (Figure 11). Figure 12 illustrates the daily cumulative adult migration.

Adult Characteristics - Age, Sex and Size

Otolith samples were collected from every 50th fish that passed through the weir (2%) in each year of the study. Otoliths were analyzed to determine age and hatchery contribution. Also recorded was weight, length and sex of each fish sampled. Table 9 summarizes the age contribution in each year. The age classes of the adult returns were 1.2, 1.3, 2.2 and 2.3. Figure 14 shows the percentage in each age class for each return year. The age-4 sockeye return
**Figure 10.** The number of adult sockeye salmon escaping to English Bay Lakes (2013–2015).

**Figure 11.** The daily cumulative escapement of adult sockeye salmon to English Bay Lakes (2013–2015).

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>0.2</th>
<th>1.1</th>
<th>0.3</th>
<th>1.2</th>
<th>0.4</th>
<th>1.3</th>
<th>2.1</th>
<th>2.2</th>
<th>2.3</th>
<th>3.2</th>
<th>3.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>12,700</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1,137</td>
<td>0</td>
<td>7,284</td>
<td>0</td>
<td>1,756</td>
<td>2,480</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2014</td>
<td>7,832</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1,194</td>
<td>0</td>
<td>4,949</td>
<td>0</td>
<td>716</td>
<td>1,003</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2015</td>
<td>6,300</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1,923</td>
<td>0</td>
<td>3,691</td>
<td>0</td>
<td>520</td>
<td>156</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Avg</td>
<td>8,944</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1,418</td>
<td>0</td>
<td>5,308</td>
<td>0</td>
<td>997</td>
<td>1,213</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>% of Avg</td>
<td>100%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>15.9%</td>
<td>0.0%</td>
<td>59.3%</td>
<td>0.00%</td>
<td>11.2%</td>
<td>13.6%</td>
<td>0.00%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Figure 12. Age class breakdown for returning adult sockeye salmon to English Bay Lakes (2013–2015).

(combination of 1.3 and 2.2) dominated the adult escapement consistently in each year. The age-3 (1.2) and age-5 (2.3) show greater variability between the different years.

The ratio of male and female in the adult escapement was consistent in all three years of the study as indicated in Table 10 below.
Unlike the smolt, the adult size, both in terms of weight and length, varied between the different years as indicated in Figure 14 and 15. As a rule of thumb, the larger the return in terms of numbers, the smaller are the fish in terms of size (Groot and Margolis, 1992). This seems to be the case for 2013 when compared to fish size in 2014. However, this did not hold true in 2015, when fish size was even lower than in 2013 despite a small fish return. Statewide, in 2015, the trend in most fishery returns was for smaller salmon in comparison to the norm. Speculation for this small size was the combination of the El Nino effect and an unusual area of warm water located in the North Pacific, affectionately referred to as "the Blob," that was influencing much of the environmental conditions during that time period (Summers, DJ., June 25, 2015).

**Adult Characteristics - Hatchery Contribution**

Data collected in 2013 had the lowest percentage (7.0% ±3.2%) of adult sockeye salmon identified as being of hatchery origin. The number of hatchery-origin fish in the escaping population nearly doubled with 14.7% (±5.4%) and 13.1% (±6.0%) in 2014 and 2015 respectively (Figure 16). However, as with the smolt, multiple age classes and hence brood years are associated with these returns. Table 11 illustrates which brood years contributed to the return in a particular year.

<table>
<thead>
<tr>
<th>Year</th>
<th>% Male</th>
<th>% Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>47.9</td>
<td>52.1</td>
</tr>
<tr>
<td>2014</td>
<td>43.9</td>
<td>56.1</td>
</tr>
<tr>
<td>2015</td>
<td>43.8</td>
<td>56.2</td>
</tr>
<tr>
<td>Avg</td>
<td>45.2</td>
<td>54.8</td>
</tr>
</tbody>
</table>

As indicated, only BY09 has had all age classes return at the end of this study. Figure 17 demonstrates the age class breakdown as well as hatchery contribution for the completed year class (BY09). Of the 7,045 adult sockeye salmon that returned from BY09, 1,592 (22.6%) were from the hatchery stocking program and the remainder (77.4%) were from natural production. With only one completed year class and no estimation on the harvest, no conclusion can be made as to differences in marine survival between hatchery- and natural- produced fish.
Figure 13. Average weight (kg) of adult sockeye salmon returning to English Bay Lakes (2013–2015).

Figure 14. Average length (mm) of adult sockeye salmon returning to English Bay Lakes (2013–2015).
Table 11. Brood year contributions to adult migration in each year at English Bay Lakes.

<table>
<thead>
<tr>
<th>Return Year (Adult)</th>
<th>Adult Age</th>
<th>1.2</th>
<th>1.3</th>
<th>2.2</th>
<th>2.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>BY2009</td>
<td>BY2008</td>
<td>BY2008</td>
<td>BY2007</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>BY2010</td>
<td>BY2009</td>
<td>BY2009</td>
<td>BY2008</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>BY2011</td>
<td>BY2010</td>
<td>BY2010</td>
<td>BY2009</td>
<td></td>
</tr>
</tbody>
</table>

*Purple highlights indicate the completed brood year covered by this study.*

Figure 15. Percentage of returning adult sockeye salmon determined to be of hatchery origin on a field season basis, English Bay Lakes (2013–2015).
Figure 16. Age class breakdown for BY09 adult sockeye salmon return English Bay Lakes.
SUMMARY

In 1992, Edmundsen reported that sockeye salmon production from the English Bay Lakes system was limited by the food resource. The information collected in this report, with hatchery fish showing a reduction in weight from their size at stocking, supports Edmundsen’s conclusion. While the addition of hatchery fish did not seem to negatively impact the size of naturally-produced smolts (size was similar), the survival of hatchery fish was less than what was expected for a pre-smolt (fall fry) stocking program. The pre-smolt-to-smolt survival experienced at English Bay Lakes was similar to the survival expected for a spring fry program, but not a fall fry program. However, without adult return information from these year classes, no conclusion can be made how a fall stocking strategy impacts the marine survival.

Based on the data collected, the smolt migration has been fairly consistent averaging 127,000 smolts per year over the course of the study period. The stocking project was assessed to determine hatchery contribution to the smolt migration. Based on the monitoring data collected, the annual stocking of 200,000 fall fry increased the smolt production on average over the 3 year study period by 27.1%. The smolt population characteristics (age class, size) reported in this study is similar to that reported between 1989 and 1992.

The adult sockeye salmon migration has proven to be more variable over the same time period. Unfortunately, no information on the smolt migration for the completed year class (BY09) is available, so no speculation can be made as to how the characteristics of the smolt migration influence the marine return, if at all.
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