INTERNAL REPORT 154

STANDING CROP, PRODUCTION, AND POPULATION DYNAMICS OF SELECTED BENTHIC AND LITTORAL FISHES IN THE LAKES OF THE LAKE WASHINGTON DRAINAGE

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INTRODUCTION

The goal of the Washington Cooperative Fishery Unit in the Coniferous Forest Biome studies is to determine the standing crop, production, and population dynamics of selected benthic and littoral fishes in the lakes of the Lake Washington drainage. As mentioned in a previous report, the studies are planned in three stages in Lake Washington and Lake Sammamish: (1) development and implementation of practical sampling gear and a sampling plan to determine distribution, abundance, and relative numbers of selected species; (2) procurement of biological data on the life histories of selected species to derive necessary population parameters and trophic relationships; and (3) development of a benthic and littoral fish submodel that is compatible with the aquatic modeling effort and will allow investigations of environmental and population changes on the fish populations.

METHODS

Development and Implementation of Sampling Gear and Sampling Plan

Stage 1 for Lake Washington was completed by the end of June 1973 following a six week intensive sampling period. Over 60 separate sample locations were used and over 2880 net hours of gillnet fishing were carried out. Stage 1 for Lake Sammamish was begun following the intensive Lake Washington sampling period. Bimonthly samples were taken during the summer, and monthly samples were taken during the fall.

Biological Data on Life Histories

Stage 2 was almost completed for both Lake Washington and Lake Sammamish in 1973; one thesis on life history was completed and two others are in draft stage. Nishimoto (1973) summarized the life history of the peamouth (Mylocheilus caurinus). From a sample of over 1700 fish, Nishimoto described length-weight relationships, reproductive parameters, basic food habits, and growth relationships of the peamouth.

Kenneth Imamura completed a draft of his MS thesis on the life history of the brown bullhead in Lake Washington. Expected to be completed in Spring 1974, this thesis will summarize age and growth relationships, food habits, and reproductive parameters of this abundant and important littoral fish, as well as provide data necessary to establish mortality rates and relative abundance.

Fred Olney has completed a draft of his MS thesis on the northern squawfish. His thesis, to be completed spring quarter 1973, will document the life history
of this long-lived fish, which is predatory on other fish. It will contain data on age and growth relationships, food habits, and reproductive parameters of the squawfish.

Benthic and Littoral Fish Submodel

Stage 3 was begun in 1973 by Norman Bartoo. It was decided that the Lake Washington benthic and littoral fish model should include information production, standing crop, loss, fecundity, recruitment, and growth and death for each age group of the abundant species in the lake. The peamouth (Mylocheilus caurinus) was chosen as the first species to be used in developing the model because of the availability of data.

Biomass movement

Because of available information, a biomass movement submodel was constructed and computerized. This model, driven by temperature and time, simulates the observed migrations of the peamouth in Lake Washington by season. Figure 1 shows the results of the simulation as compared with observed data. The movement of a portion of the biomass from one region of the lake to another can be represented by the exponential decay function:

\[ V(i)_t = V(i)_0 e^{-rt} \]

where \( V(i)_t \) = biomass or standing crop in region \( i \) after time \( t \), \( V(i)_0 \) = initial biomass or standing crop in region \( i \) at \( t = 0 \), \( r \) = constant movement rate during time period \( t \), and \( t \) = time period.

Although some refining is needed, the calculated fit shown in Figure 1 is reasonable when compared with the observed data.

Estimate of survival and population numbers

Survival and mortality rates, as well as population numbers by age group, all necessary for the general model, were estimated from catch curves obtained from Nishimoto (1973). The Appendix is a complete description of the estimation procedures used. Included in the Appendix is a table that estimates the standing crop as 10,215 kg (ages 2 to 9). In order to check the graphical method that was used to calculate the survival rate, an analytic method described in Ricker (1958) was used. This method bases the estimated survival rate \( \hat{S} \) on the relationship

\[ \hat{S} = 1 - \alpha \]

where \( \alpha \) = annual mortality rate.

For peamouth, using raw catch numbers for the ages 6-8 (where the fish are completely recruited to the gear), the expression below was used, and assumes a constant mortality rate from age 6 to death:

\[ \alpha = \frac{N_6}{N_6 + N_7 + N_8} \]
where \( a \) = annual mortality rate, \( N_i \) = number of age \( i \) fish caught, and \( S = 1 - a \). The calculated value of \( S = 0.18 \) agrees exactly with graphical method.

**Estimate of production**

The basic model used was:

\[
P = GB
\]

\[
G = \frac{\log \bar{W}}{\Delta t} - \frac{\log \bar{W}}{\Delta t}
\]

\[
B = B_1(e^{G-Z} - 1) \text{ if } (G > Z)
\]

or \( B = \frac{B_1(1 - e^{-(Z-G)})}{G - Z} \) if \( (G < Z) \)

where \( P \) = production, \( G \) = instantaneous growth, \( B \) = mean biomass in time period \( t_2 - t_1(\Delta t) \), \( B_1 \) = biomass at \( t_1 \), \( Z \) = instantaneous rate of mortality, and \( N \) = number of individuals. These equations are from Ricker (1971).

**Growth**

A model was developed to fit Nishimoto's (1973) data for weight growth versus age. Best fit to the data was given by the von Bertalanffy growth curve, \( w = (1 - b e^{-kt})^3 \), where \( b \) and \( k \) are population-specific constants and \( w \) is percentage of asymptotic weight achieved time \( t \). The equation now in use is:

\[
W_t = (1 - e^{-(0.4676)})^3 550
\]

where \( W_t \) = weight of individual at time \( t \).

**PLANNED FUTURE WORK**

During 1974, stages 1 and 2 will be completed for Lake Sammamish. Intensive sampling for relative fish numbers will be done during the spring or summer. Also during 1974, the life history of the coarsescale sucker *Cottostomus macrocheilus*, an abundant fish in both Lake Washington and Lake Sammamish, will be done. Stage 3 will be continued during 1974 and a benthic and littoral fish model will be produced and evaluated.

**APPENDIX: ESTIMATION OF LAKE WASHINGTON PEAMOUTH POPULATION NUMBERS SURVIVAL, AND MORTALITY RATES**

The peamouth population and biomass estimates done here are based on gill-net catch statistics used to establish the natural mortality rate and a combination of trawl and echo sounders to estimate the numbers of a small but identifiable peamouth subpopulation. Actual population numbers of various year classes of fish can then be calculated.

Using the entire 1971 peamouth catch by Nishimoto, numbers caught versus fish age were plotted on semilog paper (Figure 1). This is termed a *catch*
curve by Ricker (1958), and the straight right-hand tail represents the portion recruited and available to the sampling gear with similar efficiency (not necessarily 100%). As suggested by Ricker, the straight right-hand tail in Figure 1 represents similar sampling efficiency for large fish if a constant mortality is assumed. It is reasonable to assume a constant mortality for these large fish as they are not readily susceptible to predation and are fairly close in size and habits. The catch curve in Figure 2 (Hansen 1972), using peamouth gill-net catch data from the same gill nets, is similar to the curve in Figure 1 when plotted on semilog paper. Hansen (1972) showed that because the selectivity curves (in terms of length) overlapped more for larger fish than smaller fish when an arithmetic progression of mesh sizes was used for sampling, the larger (and older) fish were sampled with greater efficiency as related to age for peamouth in Lake Washington, where a straight line extended through the right leg represents the observed 100% efficiency line.

Ricker (1958) states that the right-hand leg of sampling catch curve can be used to estimate the mortality and survival of a large portion of the population curve if the ages in question are fully recruited to the gear and constant mortality rates are assumed for the ages in question. Figure 2 shows the catch curve expressed in percentage of frequency versus age with the constant mortality rate drawn in. For the portion of the graph where the catch curve is straight, a constant mortality rate is realistic for the previously mentioned reasons. This region includes fish five to eight years old. A slightly more risky assumption is involved in extending the linear or constant mortality rate from the region in Figure 1 of full recruitment (right-hand leg of Figure 1) back to younger fish. If we assume that the mortality rate becomes constant or nearly so once the fish are in their second year of life, and are larger than the food consumed by their principal predators, then we can extend the linear mortality rate to fish that are in their second year of life. In Lake Washington, larger peamouth have one principal predator, the northern squawfish, *Ptychocheilus oregonensis*. Fred Olney has indicated that squawfish remains in the stomach are seldom over 100 mm long (personal communication). This corresponds to peamouth of a maximum age 1.5 years. Using this as a cutoff point we can extend the constant mortality rate back to fish of roughly 1.5 years of age (Figure 2). Figure 2 now represents the log-normal shape of the peamouth population curve in Lake Washington.

Using trawl and echo-sounding data by Jim Traynor, the estimated peamouth population number for fish in the length range of 110 to 150 mm is 112, 646 ± 47, 313 (± 2 confidence interval). From Nishimoto (1973) we find this length range corresponds to fish of roughly 1.5 to 2 years of age. We now have a "time = 0" population estimate at the beginning of the constant mortality rate. From this we can estimate numbers of fish in each age group.

From Ricker (1958) the following estimate of mortality and survival rates were computed using Figure 2.

\[
\text{Instantaneous survival rate} = 5.59 \\
\text{Instantaneous mortality rate} = 1.72 \\
\text{Annual survival rate} = 0.18 \\
\text{Annual mortality rate} = 0.817
\]
The continuous model that could fit the situation is logarithmic:

\[ N_t = N_0 e^{-mt} \]

where \( N \) = initial population number, \( N_t \) = population at time \( t \), \( mt \) = mortality rate, and \( t \) = time. The discrete model suited for this situation is the Malthus model:

\[ N_{t+1} = N_t R = N_t = N_0 R^{t-1} \]

where \( R \) = annual survival rate and \( t \) = time in years.

Using the discrete model, which is appropriate since we are interested in the number of surviving fish at each age, the following estimates were obtained:

**ESTIMATED FISH NUMBERS**

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>Nominal</th>
<th>Nominal 2</th>
<th>C.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>112,646</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>20,580</td>
<td>29,225</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3,760</td>
<td>5,339</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>687</td>
<td>975</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>126</td>
<td>178</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>23</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>4</td>
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</tr>
<tr>
<td>9</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
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</table>

From these estimates, we calculate the mean age of the peamouth under the assumed linear mortality rate to be 2.2 years.

Table 2 shows the biomass estimates for peamouth by age group as well as the total fish biomass for peamouth age 2 and up. The mean weight/age group was calculated from all gill-net fish.

**REFERENCES**


Table 1. Yearly production of peamouth by age groups.

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Weight (g)</th>
<th>Instantaneous growth rate ( G )</th>
<th>Stock numbers ( N_t )</th>
<th>Biomass at ( B_1 ) (kg)</th>
<th>Instantaneous mortality coefficient ( Z )</th>
<th>Mean biomass ( B ) (kg)</th>
<th>Production ( P ) (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>( t_1 )</td>
<td>63.3</td>
<td>112,646</td>
<td>7130.4</td>
<td>1.699</td>
<td>13,318.0</td>
<td>7418.1</td>
</tr>
<tr>
<td></td>
<td>( t_2 )</td>
<td>110.0</td>
<td>20,580</td>
<td></td>
<td>1.699</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>( t_1 )</td>
<td>110.0</td>
<td>20,580</td>
<td>2263.8</td>
<td>1.699</td>
<td></td>
<td>-12,263.7</td>
</tr>
<tr>
<td></td>
<td>( t_2 )</td>
<td>163.1</td>
<td>3,760</td>
<td></td>
<td>1.699</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>( t_1 )</td>
<td>163.1</td>
<td>3,760</td>
<td>612.8</td>
<td>1.699</td>
<td></td>
<td>-340.2</td>
</tr>
<tr>
<td></td>
<td>( t_2 )</td>
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<td>687</td>
<td></td>
<td>1.696</td>
<td></td>
<td>-85.7</td>
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<td>5</td>
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<td>163.5</td>
<td>1.696</td>
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<td>-18.7</td>
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<td></td>
<td>( t_2 )</td>
<td>299.0</td>
<td>126</td>
<td>37.7</td>
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<tr>
<td>6</td>
<td>( t_1 )</td>
<td>299.0</td>
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<td>1.749</td>
<td></td>
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<tr>
<td></td>
<td>( t_2 )</td>
<td>325.0</td>
<td>23</td>
<td>7.5</td>
<td>1.749</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>( t_1 )</td>
<td>325.0</td>
<td>23</td>
<td>7.5</td>
<td>1.749</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( t_2 )</td>
<td>300.0</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TOTAL PRODUCTION

6771.2
Table 2. Biomass estimates for peamouth by age group.

<table>
<thead>
<tr>
<th>Age</th>
<th>Mean wt. (g)</th>
<th>1</th>
<th>Biomass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>63.3</td>
<td>16.7</td>
<td>7130.5</td>
</tr>
<tr>
<td>3</td>
<td>110.0</td>
<td>38.0</td>
<td>2263.8</td>
</tr>
<tr>
<td>4</td>
<td>163.1</td>
<td>45.0</td>
<td>612.8</td>
</tr>
<tr>
<td>5</td>
<td>238.0</td>
<td>52.9</td>
<td>163.5</td>
</tr>
<tr>
<td>6</td>
<td>299.0</td>
<td>61.0</td>
<td>37.7</td>
</tr>
<tr>
<td>7</td>
<td>325.0</td>
<td>37.0</td>
<td>6.9</td>
</tr>
<tr>
<td>8</td>
<td>300.0</td>
<td>60.0</td>
<td>1.2</td>
</tr>
<tr>
<td>9</td>
<td>300.0</td>
<td>60.0</td>
<td>0.3</td>
</tr>
</tbody>
</table>

TOTAL (all age groups) 10,215.9
Figure 1. Predicted --- and observed o o peamouth biomass distribution in Lake Washington.
Appendix: Figure 1. Numbers of peamouth captured versus age
Appendix: Figure 2. Frequency of fish captured versus age.