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SYSTEMS MODELING OF SOCKEYE SALMON IN THE WOOD RIVER LAKES

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INTRODUCTION

Sockeye salmon lake systems are characterized by high variability in the annual returns of adults. In addition some stocks have declined significantly since the inception of the commercial fishery. The most notable decline in production in Bristol Bay has occurred in the Nushagak District where the average annual catches have dropped from five million in the early period of the fishery to one million in recent years (Mathisen, 1971). The continued low production, since 1949, has made a reevaluation of past management goals and objectives essential.

Because of the complexity and influence of a number of factors, the only satisfactory way to study the long-term dynamics of a run of sockeye salmon is to construct a model of the system, whose behavior can be studied on a computer. In studying the dynamics of the salmon run in the Wood River lakes, we need to incorporate in the model processes which generate mortality at various stages in the sockeye salmon life history. In addition, the run must be partitioned into the spawning colonies characterized by differing age structure, fecundity, and survival of eggs and alevins.

If models are constructed this way, we can study hypothesized effects of the fishery. Particularly gill net selection with respect to size, and by incorporating differential timing of the run for the various spawning colonies we can study spawning colony specific rates of exploitation.

The role of the food-producing capacity of the nursery lake on the dynamics of the run of salmon to the lake is difficult to ascertain. The trophic status and productivity of a lake is important in determining what size will be achieved by a population of salmon during freshwater residence. Certainly there may be mortality due directly to lack of food. If there is mortality due directly to starvation it is likely to occur during emergence or during periods when the lake is covered with ice. These are stages in the sockeye life history where we have little direct observations. A rather less direct manifestation of poor growth is that the size of migrating smolts may affect marine survival.

A limnetic feeding model has been constructed. It will be used to evaluate effects of the zooplankton population on growth of salmon, as well as to evaluate the effects of the salmon population on the zooplankton population. Hopefully, from the modeling effort we can determine at what level of salmon densities does there occur a significant cropping of the food populations. Is there a significant reduction in growth because of this? No major recruitment of zooplankton occurs during the fall or winter. Also, the zooplankton populations at these times consist mainly of adult copepods. With this simplifying assumption, assuming natural mortality estimates for zooplankton from studies involving similar trophic situations, and coupled with sockeye grazing, we can simulate overwinter growth for salmon with the limnetic feeding model. It is the intention to extract from these studies the salmon population levels where density-dependent regulation occurs.

To date we have defined the gross structure of the Wood River system model. Relevant data have been assembled and exist in the Wood River Data Bank. The limnetic feeding model is programmed and running. At present we are validating the model on more detailed data that exists on the sockeye in Lake Washington.

GENERAL PLAN OF THE MODEL

The overall structure of the Wood River system model is similar to that of the model presented by Larkin and Hourston (1964). The state variable of the system is the number of individuals of a given age class and spawning colony. Thus, at any given time there exist $i \times k$ such state variables, where i = number of age classes and k = number of spawning colonies.

Changes in a given state variable occur by recruitment of fry from spawning adults and by mortality. Mortality will be treated as a process occurring at specific points in the life history. Mortality may be spawning colony specific (i.e., fishing mortality), or may affect groups of spawning colonies at the same rate (i.e., food shortages).

Specific sources of mortality, which the model will deal with, are:

1) Mortality due directly by overcrowding on the spawning ground. This includes loss of eggs by superimposition.

2) Egg and alevin mortality during incubation due to a number of factors, including harsh winter weather conditions, predation, and variation in lake and stream hydrology.

3) Predation on fry migrating to their respective nursery lake. This may be more severe in stream and river spawning colonies than in lake beach spawning colonies.

4) Mortality in the summer littoral, summer limnetic, and winter limnetic trophic situations that the salmon encounter during the

freshwater stage of its life history. This includes predation and mortality due directly to food shortages.

5) Smolt predation by resident freshwater fishes.

6) Mortality occurring in estuarine environments on migrating smolts.

7) Natural mortality in the ocean.

8) Fishing mortality on the high seas.

9) Inshore fishing mortality.

The problem of monitoring age structure and stock composition is primarily a programming problem. It is simply a matter of updating parameters which relate this information with each change of the population.

Table 1 gives some information on the major spawning colonies of the Wood River lakes.

WOOD RIVER DATA BANK

Relevant data collected in the Wood River lakes during the long-term studies conducted by the Fisheries Research Institute have been assembled. They are stored on magnetic tape, and can be accessed through the update system utilized on the CDC 6400 here at the University of Washington. Update is a system program contained in the Scope 3.3 operating system for the CDC 6000 computer series. For a reference on use of update consult the Scope 3.3 reference manual. Update is used to create, manipulate and maintain library files.

The Wood River Data Bank consists of a number of files. Each file covers a specific area of interest (e.g., all data on primary productivity is contained in one file). Each file contains appropriate description of all the data that it contains; included are all relevant information and units.

A file is a linear sequence of information.

The file structure of the Wood River Data Bank is diagrammed in Figure 1. The first deck is a file description, which relates the area of interest of that file. The second deck is the description of the succeeding data decks. The decks are described in the order that they follow. Following the data description are the data decks. Each deck is punched according to the same format to facilitate description as well as usage.

Table 1. Information on the major spawning colonies of the Wood River lakes. The statistics presented are averaged over all years that data exist for the respective spawning colonies

			Proportion of total run			
Name of spawning colony	Nursery lake	Type of spawning	2-ocean adults	3-ocean adults	1+ fresh-water age adults	2+ fresh water age adults
Hansen Creek	Aleknagik	Creek	.796	.201	.869	.131
Happy Creek	Aleknagik	Creek	.505	.494	.847	.153
Bear Creek	Aleknagik	Creek	.544	.459	.882	.118
Ice Creek	Aleknagik	Creek	.314	.685	.904	.096
Agulowak River	Aleknagik	River	.214	.786	.860	.140
Fenno Creek	Nerka	Creek	.812	.182	.941	.059
Stovall Creek	Nerka	Creek	.764	.234	.978	.022
Lynx Creek	Nerka	Creek	.813	.184	.950	.050
N4-N6 Beaches	Nerka	Beaches	.662	.334	.935	.065
Pick Creek	Nerka	Creek	.806	.192	.973	.027
Little Togiak River	Nerka	River	.613	.386	.941	.059
Anvil Bay Beach	Nerka	Beach	.731	.268	.941	.059
Hidden Lake Creek	Nerka	Creek	.915	.083	.977	.023
Kema Creek	Nerka	Creek	.752	.246	.949	.051
Agulukpak River	Nerka	River	.292	.708	.905	.095
Little Togiak Beaches	Little Togiak	Beaches	.642	.358	.846	.154
Moose Creek	Beverley	Creek	.790	.207	.952	.048
B9 - B12 Beaches	Beverley	Beaches	.890	.107	.815	.185
Hardluck Bay Beaches	Beverley	Beaches	.851	.146	.826	.174
Silver Horn Beaches	Beverley	Beaches	.855	.141	.848	.152
Northwest Mikchalk Beaches	Beverley and Mikchalk	Beaches	.814	.183	.805	.195
Kulik Beaches	Kulik	Beaches	.885	.105	.701	.299
Grant River	Kulik	River	.786	.212	.813	.188

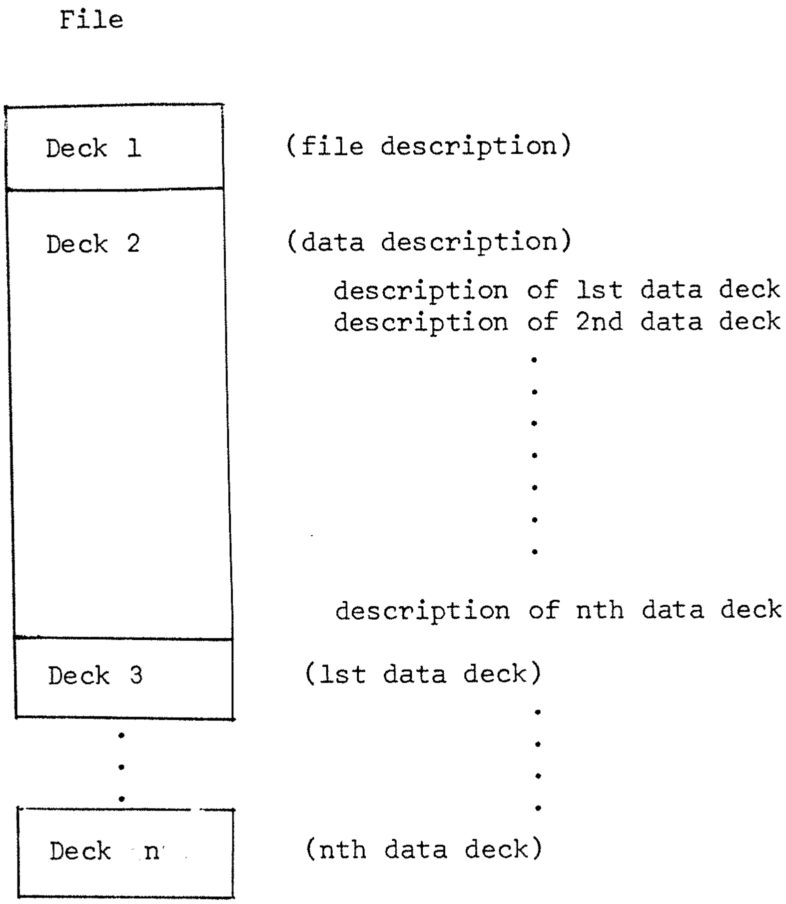

Figure 1. File structure of the Wood River Data Bank.

The outstanding feature of this Data Bank structure is that it is in update and therefore can be easily amended and subsequent years of data can be added readily. Also by use of file manipulating capacity of the Scope operating system the information contained in the Data Bank can be retrieved easily and inputted into various statistical program packages, graphing routines, as well as any Fortran program we wish to construct, for data analysis and model verification. A description of current files in the Wood River Data Bank is given in Table 2.

STRUCTURE OF THE LIMNETIC FEEDING MODEL

The model consists of two components, a growth simulator and a food consumption submodel. The first component will give inputs of ration and water temperature, relate change in body size over time. This submodel is based on the classical energy budget approach to the growth of fishes.

$$pR = T_{SDA} + T_S + T_A + \Delta W$$

Where:

pR = ration

p = assimilation coefficient

T_{SDA} = energy of specific dynamic action

T_S = energy of standard metabolism

T_A = energy of activity

ΔW = growth

There is a system of differential equations relating energy flow between the above compartments. These equations depend upon temperature and body weight. The use of temperature in the model gives us the capacity to evaluate seasonal changes in temperature, as well as diurnal changes in temperature due to vertical migration on growth.

The second component of the limnetic feeding model is a food consumption submodel. This submodel determines the quantity of food ingestion (ration), given information on zooplankton food population (species composition, density, particle size, and vertical distribution of species). The submodel is based on the extensive modeling by Holling (1966) of the functional response of predation to prey density. It is an extension of the disk equation to a multiple prey situation. The form of the model is:

Table 2. Current files on the Wood River Data Bank

File No.	Area covered
1	Contains variables with yearly values (relates gross features of the system)
2	Primary productivity
3	Secondary productivity
4	Physical and chemical data
5	Escapement, return, and stock composition
6	Resident fish
7	Abundance and growth of juvenile sockeye salmon and potentially competitive species
8	Fishery records

$$E_T = \left[\frac{\Sigma a_i N_i S_i P_i E_i}{1 + \Sigma a_i N_i P_i Th_i} \right] T$$

where T = time spent foraging

E_T = energy ingested in T

N_i = density of prey i

a_i = encounter rate of prey i

P_i = prob {pursuit/encounter} for prey i

S_i = prob {capture/pursuit} for prey i

Th_i = expected time for pursuit, capture, and eating one prey type i

E_i = energy content in prey i

There are equations which express the value of these parameters. Encounter rates are based on the geometry of the field of vision for a predator with binocular vision. Length of the prey is taken into account, as larger prey are encountered more frequently than smaller prey. The caloric content of a prey item is a function of the size of that prey item. The capture probability is lower for copepods because of the darting ability of copepods.

Through appropriate mathematical analysis of the model, there exists, under certain circumstances of prey distribution, an optimal strategy, such that E_T is maximized. This strategy is expressed as a vector of pursuit probabilities $\{P_i\}$. There is evidence that sockeye may feed in this manner when exploiting a zooplankton population, whose constituent species are of sufficient densities and particle sizes.

It is now easy, given the above model to generate growth rates for sockeye under a number of hypothesized situations, by treating the characteristics of the zooplankton population as an independent variable. Thus we observe growth of sockeye as the response to this variable. It is of great interest to determine what zooplankton population characteristics yield low or negative growth rates. We must ascertain if these do in fact occur regularly in natural situations, and if they are products of variation in prey abundance independent of the salmon or are they the result of cropping by the salmon. Answering these questions is important in determining whether the Wood River lakes are food-limiting.

In the final analysis we will not be able to include a submodel of this complexity in our model relating the run dynamics of the Wood River lakes. The detailed analysis of the limnetic feeding model will allow us to make simplifying assumptions relating to mortality due to shortages of food and density dependence. These will be included in the final synthesis as stochastic variables or as density-dependent processes.

LITERATURE CITED

Control Data Corporation. 1971. Scope reference manual, 6000 version 3.3.

Holling, C. S. 1966. The functional response of invertebrate predators to prey densities. Memoirs of the Entomological Society of Canada 48:1-86.

Larkin, P. A., and A. S. Hourston. 1964. A model for simulation of the population biology of Pacific salmon. J. Fish. Res. Bd. Canada 21(5):1245-1265.

Mathisen, O. A. 1971. Escapement levels and productivity of the Nushagak sockeye salmon run from 1908-1966. Fishery Bulletin 69: 747-763.