FRI-UW-7601
June 1976

SYSTEMS MODELING OF SOCKEYE SALMON IN THE WOOD RIVER LAKES

by

Donald E. Rogers

FINAL REPORT

Anadromous Fish Project

Project No. AFC-44
Grant No. 04-5-208-65
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Date: June 3, 1976

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This project was financed in part with Anadromous Fish Act (P.L. 89-304) funds through the National Marine Fisheries Service.

Approved

Submitted June 3, 1976

[signature]
Director

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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).

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 (the major producers in the district), we need to incorporate processes which generate mortality at various stages in the sockeye salmon life history. In addition, the run (stock) must be partitioned into spawning colonies (races) characterized by differing age structure, fecundity, growth and survival of eggs and alevins.

Three major components of the systems model limit or control under certain conditions the production of sockeye salmon in the Wood River lakes: (1) The amount of spawning area available, (2) The food-producing capacity of the lakes, and (3) Predation, especially by Arctic char and humans. The purpose of this study was to define the components and their interrelationships within the limits of existing data so that the annual variation and long-term trends in abundance of sockeye salmon could be explained and management alternatives provided to achieve maximum sustainable yield to the presently depressed commercial fishery.

The first five months of this study (February 1, 1973 to June 30, 1973) were spent in theoretical development of the model, construction of a data bank, and compilation of reports and publications on studies in the Wood River lakes from 1946 to the present (Eggers and Rogers 1973). During July 1, 1973 to June 30, 1974 we examined relationships between the abundance of spawners (escapement) and their returning adult progeny because the spawner-return relationship has formed the basis for past management of the Wood River stock (Rogers 1974). During July 1, 1974 to June 30, 1975 we examined the interrelationships among freshwater growth, survival, and effects of the physical environment (Rogers 1975).

The annual reports contain descriptions of methods and statistical relationships, summaries of data, and references. This report presents a review of the important conclusions.

ADULT ESCAPEMENTS AND RETURNS

Considering the decline in abundance that occurred from 1946-1948 to the present among the three major stocks in the Nushagak (Wood River, Igushik, Nuyakuk, Figs. 1 and 2), the present age composition of the stocks (Wood River predominantly 2-ocean fish and the others predominantly 3-ocean fish), and the present productivity of the stocks it was concluded that the decline in the Nushagak fishery was caused by a decline in the abundance of the Wood River stock. The selectivity of the gill-net fishery has altered the sex and age composition of the spawning stock through differential mortality on the races in the lake system. Although the fishery probably affected the productive capacity of the Wood River stock, the major declines in abundance were associated with the quantity rather than quality of spawners. Major declines in the runs followed years of large escapements (descending limb of spawner-return curve), thus under exploitation in some years probably contributed more to the decline in abundance than did over exploitation.

It has often been impossible to achieve optimum escapements to the individual spawning grounds in the lake system because of frequent lack of correlation in the abundance of runs to the spawning grounds. Nevertheless, the average escapements to the spawning grounds have been close to the optimum number and still the returns have declined for the majority of the races. Presently the most productive populations per unit size (river spawners) receive the highest rate of exploitation and the least productive per unit size (beach spawners) receive the lowest rate of exploitation.

The calculated optimum escapements (Ricker-type curve) ranged from 1,350 to 2,100 spawners per km^2 of lake surface area for the individual lakes in the system. The optimum escapement for the lake system is about 700,000 (1,600 per km^2 of surface area). However, over a large range of escapements from 400,000 to 1 million there is little difference in the average return. The largest returns in recent years have occurred when escapements were between 1 and 1.5 million but escapements greater than 1.5 million have resulted in returns that numbered less than the parent escapement.

There is a cyclic abundance in the runs of beach spawners (predominantly in Lakes Beverley and Kulik, Fig. 3). Very low runs occur every four years and this cycle is maintained by the combination of age at return for adjacent brood years and a lower than average production (return per spawner) for the low-cycle brood year or line. The optimum escapement to the lake system in these low-cycle years (e.g., 1965, 1969, 1973, and 1977) should be based on the optimum escapement to Lake Aleknagik plus Nerka that is about 400,000 fish.

The beach spawning populations appear to offer the greatest potential for increasing the total abundance of the annual runs to the Nushagak fishery; however, such an increase cannot be achieved simply by regulation of fishing mortality or obtaining calculated optimum escapements to the lake system because such escapements in the recent period of the fishery have not produced the large returns that they formerly produced (Fig. 4). The reasons for the historical decline in return per spawner probably lie in the freshwater phase of the life history of the Wood River sockeye.

ABUNDANCE AND GROWTH OF JUVENILES

Mathematical models were used to approximate the relationships between the abundance of sockeye salmon at various stages in their life history. Simple models, e.g., linear and second degree polynomial, were used because the amount of data (13 years) did not seem to justify more complex models. There was considerable variation around the lines or curves that were used to describe the statistical relationships between abundances. Much of this variation was likely associated with sampling error in estimating the abundance of fish. Nevertheless some apparently significant differences were evident between lakes in the Wood River system.

The relationship between the number of fry produced (late summer) and the number of eggs in the parent escapement was approximately linear for each of the lakes in the system. Survival from eggs to fry was greater in Lake Aleknagik than in the other lakes; however, this difference may have been caused by differences in the availability of fry to sampling. There was a significant correlation between survival from eggs to fry and the average air temperature during the winter for the populations in Lakes Beverley and Kulik that are primarily beach spawners. However, no correlation was evident when abundance of spawners was low.

The growth of fry during the summer was partially density dependent. As the density of eggs and fry increases the size of the fry by September decreases. At low densities of eggs the fry were not as large in the upper lakes of the system and at high densities of eggs they were not as small in these lakes as they were in Lakes Aleknagik and Nerka. The upper lakes have a shorter ice-free period and probably produce less food for sockeye fry; however, the populations of threespine stickleback (main competitors with sockeye fry) were not as dense in these lakes as they were in Lake Aleknagik. The growth of the threespine stickleback was dependent on the abundance of sockeye, i.e., the higher the density of sockeye the poorer the growth of sticklebacks.

As a result of the density-dependent growth the relationships between weight (biomass) of fry produced and the number of parent eggs were curvilinear. The decrease in average biomass of fry at high densities of eggs was most pronounced in Lake Aleknagik. In the other lakes, the biomass of fry increased only slightly as the abundance of fish increase above the average.

Relationships between the number of adults produced and the number or weight of fry appeared nearly linear for the upper lakes of the system and curvilinear for Aleknagik and Nerka. The maximum adult return occurred near the maximum abundance of fry that has been observed in each of the lakes. Thus, since 1958, the fry populations in the lakes in late summer have usually been within the carrying capacity of the spawning grounds (egg to fry relationships) but at the highest abundance of fry there has been a slight decrease in the production of adults.

Except for populations in Lake Aleknagik, there were significant correlations between survival from fry to adults and the mean weight of the fry. Thus the growth of the fry had some effect on their ability to survive for those populations farthest from the outlet of the lake system. These fish would be more subjected to predation by Arctic char when migrating as smolts than those from Lake Aleknagik.

The growth of the fry or their size at the end of their first summer also affects their age at smoltification. The sockeye salmon in the Wood River lakes usually migrate to sea as yearlings; however, when fry populations are large and growth is poor some of the fry will hold over another year and migrate as two-year-olds.

SUMMARY

The statistics for the lake system are primarily determined by those for the largest lake (Nerka with 47% of the surface area). The relationships shown in Fig. 5 are thus similar to those for Lake Nerka, although the number of fry produced in the lake system was not linear with the number of parent eggs as was the case for individual lakes. The number of fry produced decreased slightly at high abundance of parent eggs. Growth decreased with an increase in abundance and thus the biomass of fry produced increased only slightly when the abundance of eggs or the parent escapement exceeded the average for recent years. The number of returning adults was more closely correlated with the biomass of fry than with the number of fry and the returns declined at a lesser rate with a high biomass of fry than with a high number of fry.

The production of adult sockeye salmon in the Wood River lakes is presently limited by (1) the amount of spawning ground, e.g., mainly in Lake Aleknagik where there is a high proportion of creek spawning, (2) predation during lake residence and seaward migration, and (3) growth conditions in the lakes that affect the age and size of seaward migration and thus the early marine survival. Historically the escapements were no larger than at present and it is unlikely that the amount of spawning area has decreased; therefore, the decline in the abundance of adults in the Wood River system was probably the result of a decrease in growth conditions (primary and secondary productivity) and an increase in freshwater mortality from an increase in the abundance of Arctic char. Methods for increasing growth and decreasing predation are needed to provide a basis for management to increase the Wood River sockeye runs and hence the commercial catches in the Nushagak District of Bristol Bay.

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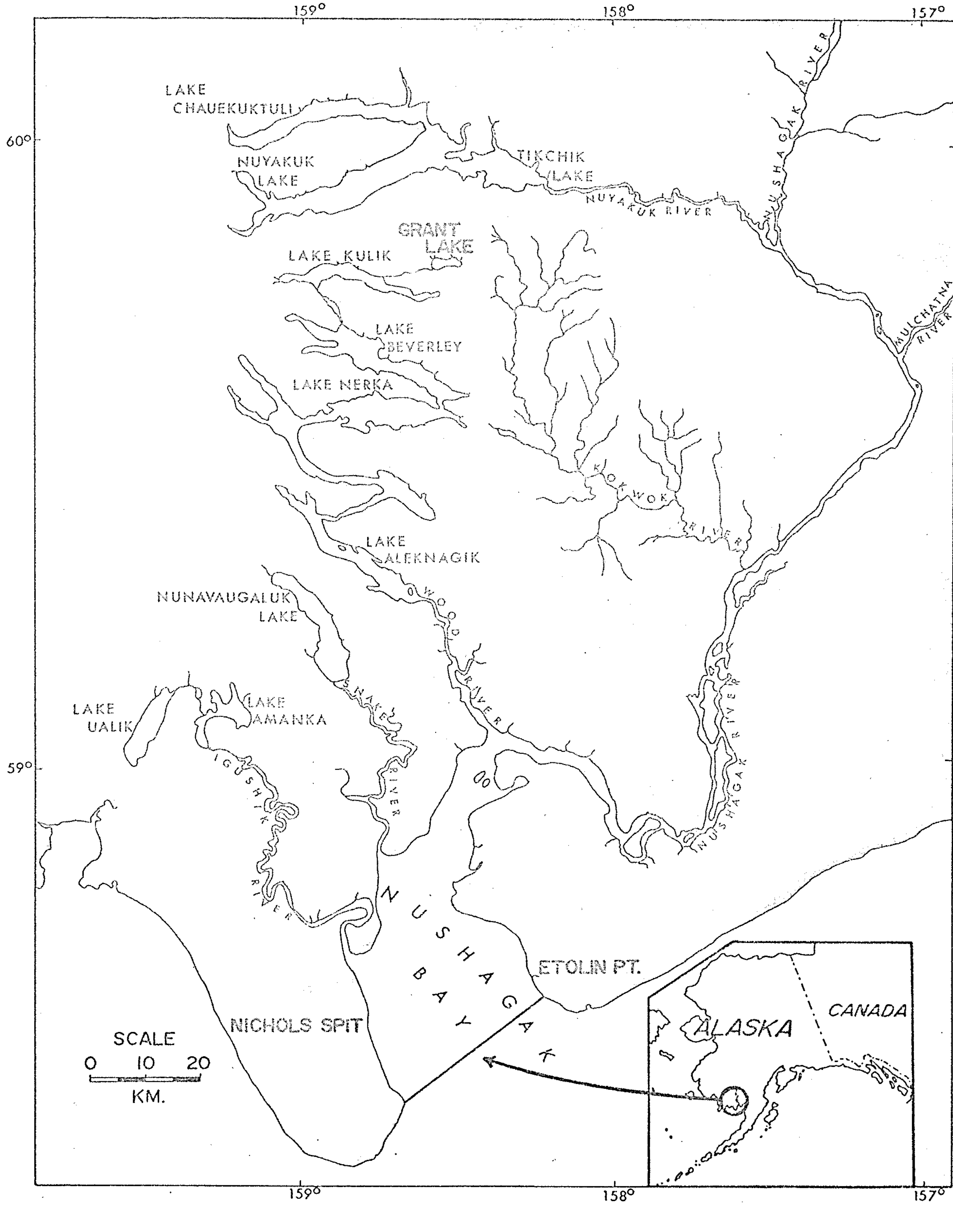

Fig. 1. The Nushagak District of Alaska showing (from north to south) the Tikchik, Wood River, Snake River, and Igushik River lake systems.

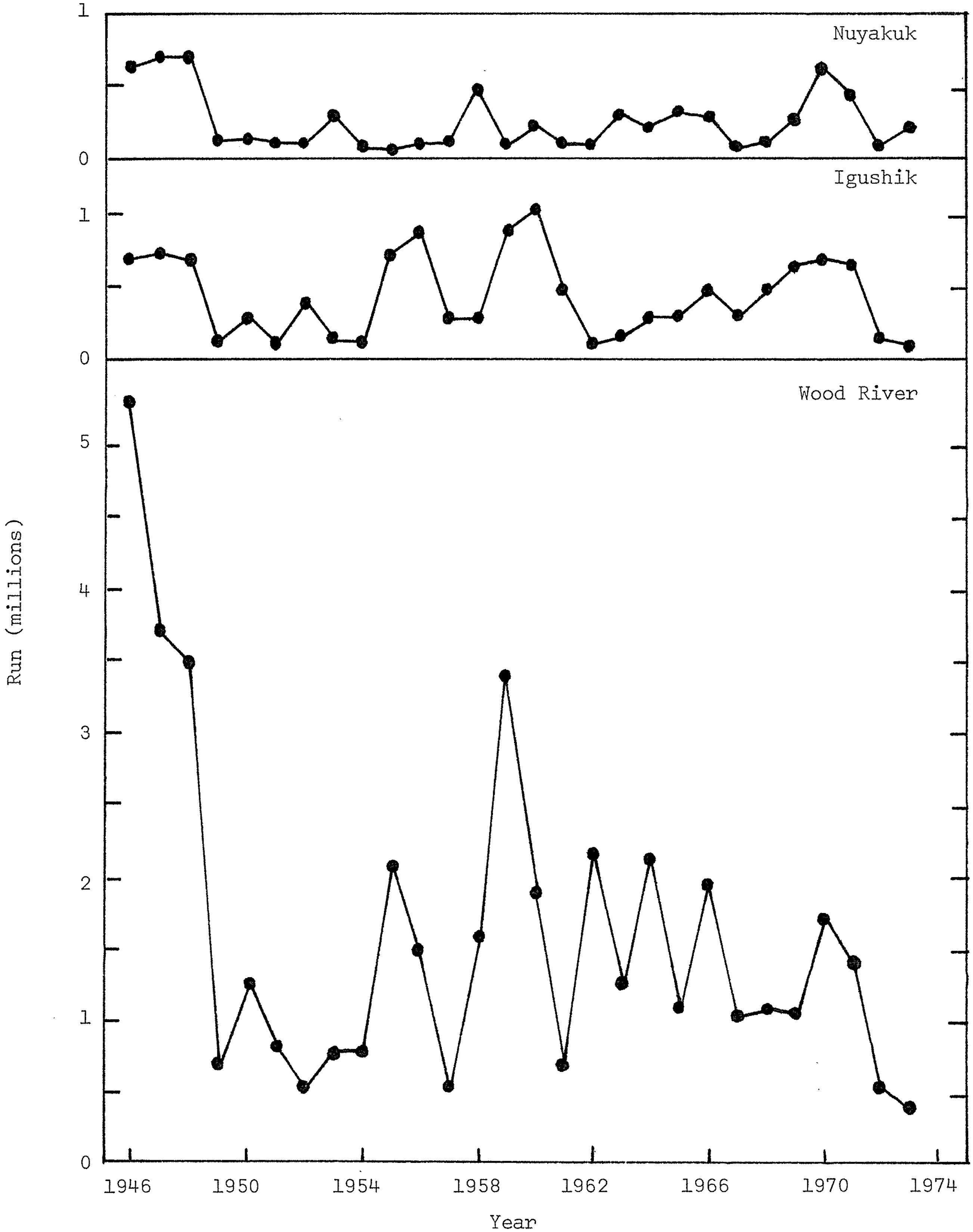

Fig. 2. Annual runs of sockeye salmon to the major lake systems of the Nushagak District, 1946-73.

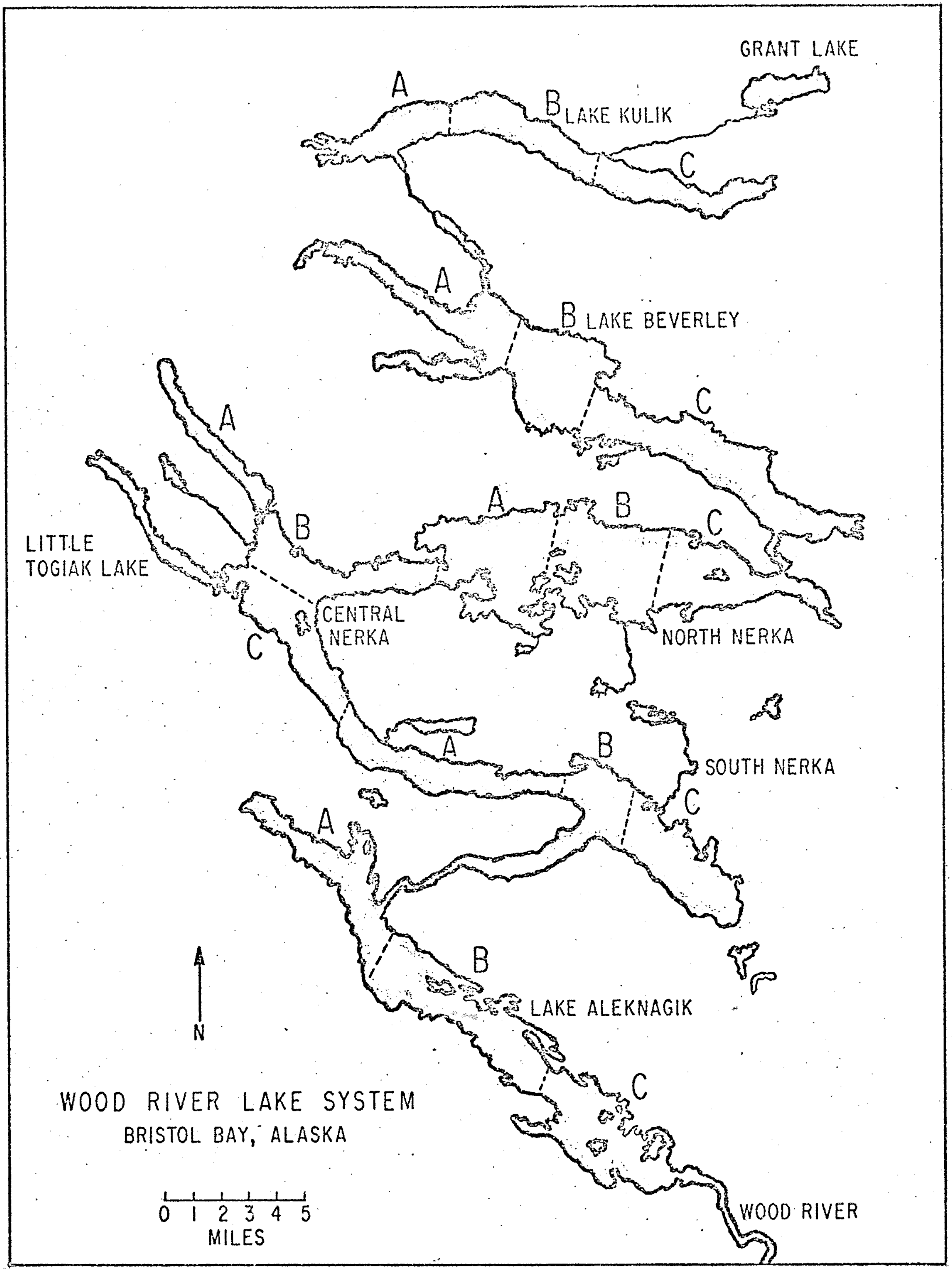

Fig. 3. Map of the Wood River lake system, showing sampling areas (A,B,C).

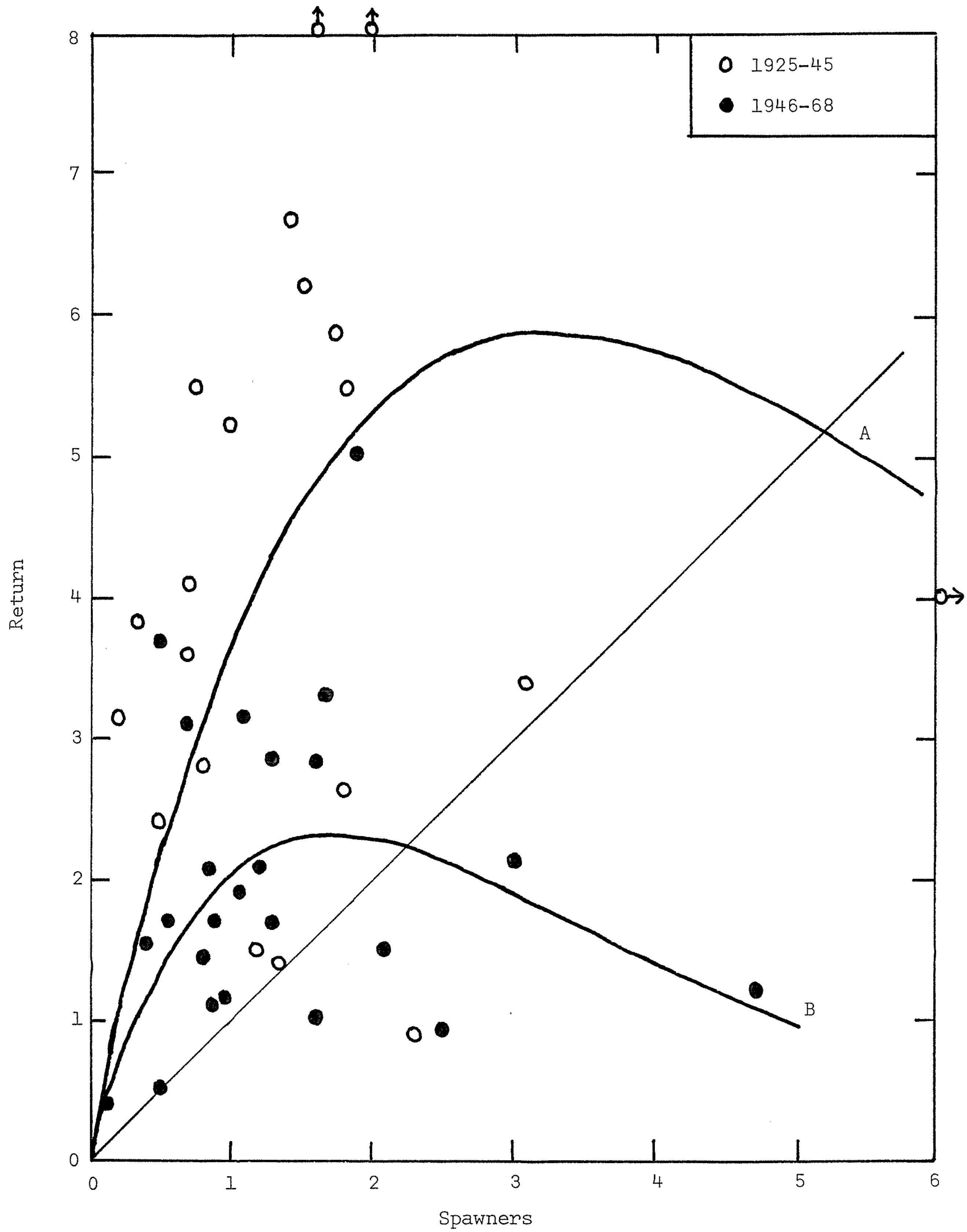

Fig. 4. Spawner return relationships for sockeye salmon in the Nushagak District.
A = 1925-45 brood years; B = 1946-68 brood years. Number of fish in millions.

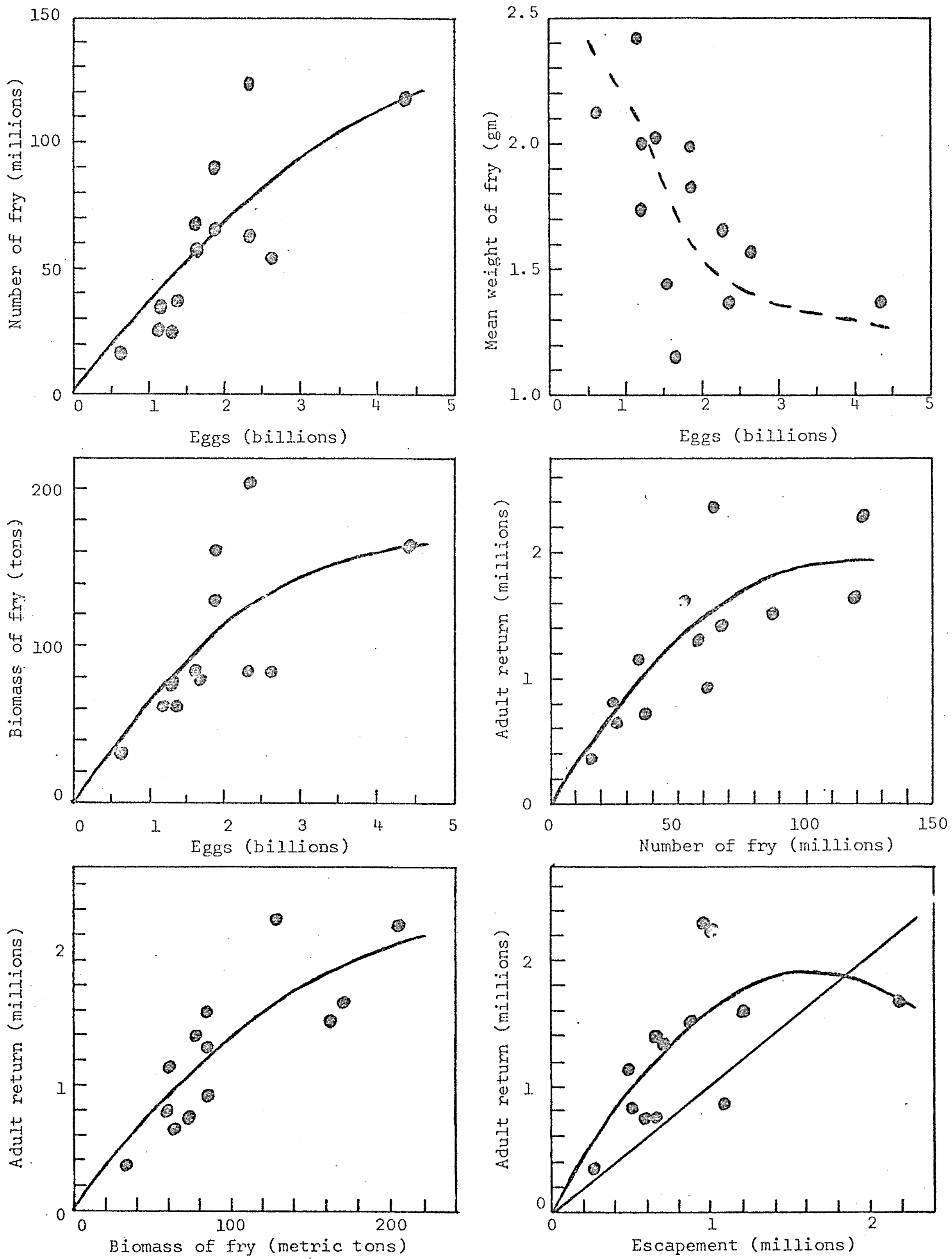

Fig. 5. Production statistics for sockeye salmon in the Wood River lakes, 1957-1969 brood years.