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Production Studies as a Focus for Assessing Juvenile Atlantic Salmon Populations

by

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Abstract

Proper management of Atlantic salmon during the freshwater phase of its life cycle will depend to a large extent on our knowledge of how salmon production in nursery streams is affected by different environmental and biological features. Production here is used in a defined biological sense, i.e., it is the rate at which biomass is being produced in the natural environment. At present, juvenile salmon populations are monitored by estimating population densities at a large number of sites once annually. I am proposing in this document that this field program should be modified so that long-term studies of production can be made; production estimates could then be used as a more effective focus for the annual assessment of the state of juvenile Atlantic salmon populations. General field procedures required for estimating the production rate of salmon in eastern Canadian streams are discussed.

Résumé

De nos connaissances sur la façon dont la production de saumons dans les cours d'eau d'alevinage est influencée par diverses caractéristiques environnementales et biologiques dépendra une gestion adéquate de cette espèce durant la phase en eau douce de son cycle biologique. Nous employons ici le terme production dans son sens biologique, c.-à-d. le taux auquel la biomasse est produite dans un environnement naturel. Présentement, on suit les populations de jeunes saumons en estimant, une fois par année, les densités de populations à un grand nombre d'endroits. Nous proposons, dans le présent document, de modifier le programme sur le terrain de façon à pouvoir effectuer des études de production à long terme; les estimations de production seraient alors le point central d'évaluations annuelles de la condition des populations de jeunes saumons atlantiques. Nous examinons les méthodes de travail sur le terrain pour estimer les taux de production du saumons dans les cours d'eau de l'est canadien.

Introduction

Freshwater habitat suitable as rearing area for juvenile Atlantic salmon in Canada is gradually decreasing because of industrial, agricultural, and foresty activities. This emphasizes the need for proper management of the remaining nursery stream habitat if natural populations of salmon are to remain healthy and self-sustaining. Power (1973) defined management as "activity designed to maintain natural stocks and increase productivity" and he emphasized that "our ability to manage Atlantic salmon will depend entirely on our ability to maintain salmon habitat." A corollary and prerequisite to this is that we understand what good freshwater salmon habitat is, and how production in nursery streams is affected by different environmental and biological features. Detailed studies of the production ecology of juvenile Atlantic salmon will, I believe, give the necessary insight into the dynamics of salmon populations to enable us to predict what environmental and biological changes will have on the salmon populations. Long-term studies of production, in all types of riverine habitats, could provide a meaningful focus for the annual assessment of the state of juvenile Atlantic salmon populations during the freshwater phase of their life cycle.

Production defined and the juvenile salmon ecosystem

Production in the biological sense is defined as the total increase in biomass of fish tissue in a defined time period, including what is formed by individuals that do not survive to the end of the time period (Ivlev 1966). Production, therefore, is a rate and is expressed as biomass per unit of area per unit of time (e.g., g per m^2 per year). Production combines information on growth and population abundance, and it is considered by LeCren (1972) to be the best parameter for describing the quantitative performance of a fish population in any type of environment. For short periods of time, production can be calculated using the simple formula $P = G_{\Delta t}\bar{B}$, where G = relative growth and $\bar{B}$ = mean biomass during the time interval Δt.

Trophic relationships leading to salmon production are complex in eastern Canadian streams. Randall (1981) summarized these relationships in a schematic diagram (Fig. 1). Aquatic benthic invertebrates and allochthonous insects which enter the stream drift form the primary food supply for the salmon. Part of these benthic food resources will also contribute to the production of other (competing?) species of fish and carnivorous invertebrates, but the largest proportion will be utilized by salmon since they are often the dominant carnivore. Food supply, along with other biotic and abiotic factors will determine the growth rate of individual salmon, and it may also influence the population density. Population numbers present at any time will depend on initial recruitment and subsequent mortality. If food resources are limiting, high population densities will also have a negative effect on growth rates. The product of population density and mean individual weight is biomass and the product of the biomass and growth is the production rate. Production rate in turn determines the new biomass. Part of salmon biomass produced in the stream will become migrant smolts and the production process will then continue in the marine environment. Adult salmon returning to spawn complete the cycle. Production in the stream commences when the salmon alevins emerge and begin utilizing the stream resources for food.

Although complex, it is important to remember all of the above components in the dynamic system leading to salmon production when trying to predict or assess the potential effects of environmental alterations on salmon populations.

Long-term objectives of production studies

The long-term goal of juvenile salmon production studies should be to determine optimum fry and parr densities in streams that will maximize production rates and smolt yields. The theoretical relationship between biomass and production has been discussed by Brocksen et al. (1970). In any environment where food is limiting, the average growth rate of fish will decrease as biomass increases. Since production rate is a product of relative growth and biomass, production will initially increase with increases in biomass, then reach a peak at some intermediate biomass level, and finally decrease at high biomass levels because of reduced growth (Fig. 2). Brocksen et al. (1970) cite studies that seem to support this theoretical relationship between biomass and production.

Juvenile salmonoids inhabiting streams are sometimes regulated by density-dependent mortality rates as well as density-dependent growth rates (Backiel and LeCren 1978), and this further complicates the relationship between population density and production. LeCren (cited in Backiel and Le Cren, op. cit.) varied brown trout densities in a field study and noted that mortality rates increased and growth rates decreased as population densities increased. The result was that production first increased with increases in population densities, and then levelled-off and remained constant, regardless of population densities above a certain threshold.

Whether production by juvenle salmon deceases at high population densities (as Brocksen et al.'s 1970 model suggests) or remains constant (as was found for brown trout, LeCren op. cit.) seems to remain an open question at present. However, the immediate problem is to determine the optimum population density that will maximize the production rate of juvenile Atlantic salmon. Densities less than optimum will reduce production, and densities greater than optimum may also reduce production or at least represent wasted recruitment.

The final "product of interest" in any study of juvenile salmon populations is the yield of smolts since this yield will eventually determine the yield of adult salmon. Recently, Elson (1975), Elson and Tuomi (1975), and Symons (1979) have attempted to estimate the optimal egg deposition required in salmon streams to optimize smolt yield. Their estimates of optimal egg deposition differ somewhat and there is also a basic difference in the theory of the stock-recruitment relationship suggested for salmon by the two authors. On the one hand, Elson's (1975) model suggests that smolt yield will first increase with increases in egg deposition, then reach a peak and finally decline at high deposition densities (Fig. 3a). Data given by Gee et al. (1978) on the relationship between initial fry densities and pre-smolt yield seems to support Elson's (1975) compensatory mortality model. Symons (1979) questioned this model, however, and presented an alternative hypothesis whereby smolt yield neither increases or decreases substantially at spawning densities above optimum (Fig. 3b).

Distinction between these two hypotheses is clearly desirable for proper salmon management. A management strategy designed to provide egg depositions above the defined optimum may provide a means of ensuring adequate smolt yields if Symons' (1979) hypothesis is correct, but this strategy would have a long-term detrimental effect on smolt yield if Elson's (1975) hypothesis is correct. Determining whether or not smolt yield is reduced at high spawning densities would require an understanding of how production of each age-class of salmon affects the production of all cohabiting cohorts, from emergent alevins to pre-smolt parr. Long-term detailed analysis of the production dynamics of salmon could provide this information. Directed research in this area would provide the information needed to refine both Elson's (1975) and Symons' (1979) stock-recruitment models.

At least two long-term production studies have been done on other species of Salmonidae. Hunt (1974) was able to evaluate what effect stream habitat alteration had on trout (Salvelinus fontinalis) production and yield of desirable-sized fish to anglers. Streambank alterations and greater instream cover increased the carrying capacity of the stream for older trout and angler harvest increased accordingly; a greater proportion of annual production was in the form of fishing-size trout. In another study, Bjornn (1978) observed the relationship between egg deposition and smolt yield of chinook salmon (Oncorhynchus tshawytscha) over a number of years. He found a positive relationship between egg deposition and smolt yield, even after natural spawning was augmented by planting hatchery fish. Juvenile chinook salmon remain in the river for only 1 yr and therefore the dynamics of these juvenile populations are not comparable to Atlantic salmon which usually smoltify after 2-4 yr in freshwater.

Similar, long-term production studies of juvenile Atlantic salmon would be beneficial. At least one short-term salmon production study has been done in eastern Canada (Randall 1981), indicating that detailed production studies are, in fact, feasible.

Field estimates of salmon production

Estimating juvenile salmon production in the field requires periodic estimates of both population densities and growth. Because of winter conditions in eastern Canada, quantitative estimates of salmon densities can only be made in spring, summer, and early fall. However, seasonal estimates of salmon growth indicate that most growth occurs during the spring and early summer, and very little growth occurs for the 7-mo period from October to May (Randall 1981; Fig. 4). Since production is the product of growth and biomass, reasonable estimates of production rate can be made if the populations are monitored during the critical growing period when the greatest changes in biomass are occurring. Estimates of production could be made, therefore, by sampling salmon populations at each site three or four times annually; once before growth accelerates in spring, once or twice during the maximum growth period, and once after most growth has ceased in autumn (Fig. 4). At each observation period, paired estimates of population density and growth would be necessary.

Production rate should be calculated for each year-class of salmon separately. Since the habitat requirements of juvenile salmon change as the salmon grow, it is important that a variety of habitat types, suitable for all age-groups of salmon, be considered when sites are selected for production studies. Underyearling salmon prefer shallow riffles (10-15 cm) with a pebble substrate, while larger parr prefer deeper water (30 cm) with a cobble-boulder substrate (Symons and Heland 1978). Maximum numbers of both fry and parr in the Miramichi River were found in areas where current velocities were 50-65 cm/sec (Symons and Heland, op. cit.). Production studies should be carried out with a suitable replication of sites that represent both preferred nursery and preferred parr habitats.

At present, juvenile salmon populations in the Miramichi River are assessed by estimating population densities at a large number of sites (86) once annually (Peppar and Schofield 1978). While the information this field census provides is valuable, production studies would increase the knowledge derived from these assessments considerably. Annual production rates can be estimated either by increasing the field effort so that density estimates are made three or four times per summer at each site (see previous), or by decreasing the number of sites and conducting more surveys at each so that the total field effort remains the same. The potential information to be gained on the dynamics of the juvenile salmon populations make this proposal worth considering.

Conclusions

Proper management during the freshwater phase of Atlantic salmon will depend to a large extent on our knowledge of the production ecology of salmon populations. Detailed production studies (as described in this report) are feasible in eastern Canada, but they would require extra field effort to that which is already expended to census the salmon populations each year. Long-term studies of salmon production could provide an effective focus for the annual assessment of salmon populations in streams.

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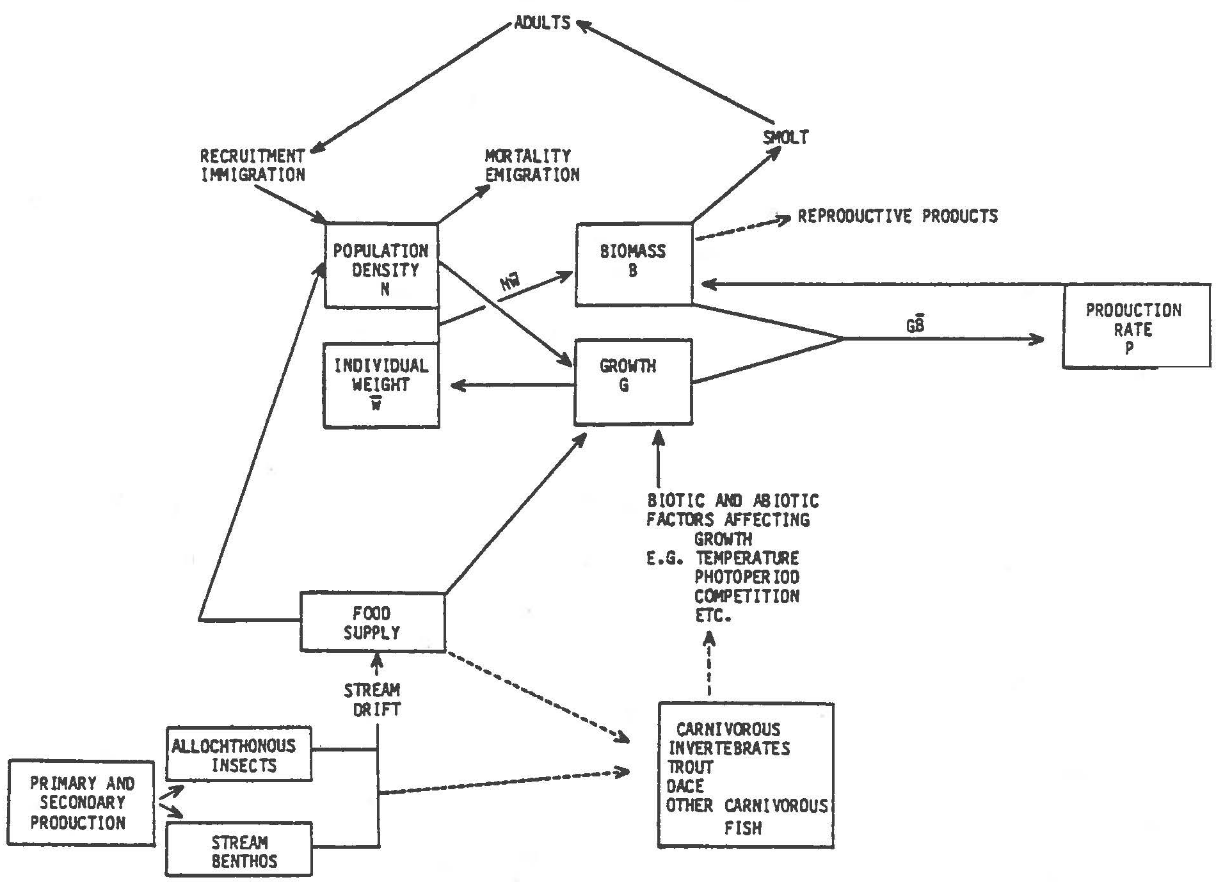

Fig. 1. Schematic diagram showing the interrelationship of components of the trophic system leading to juvenile salmon production. (From Randall 1981).

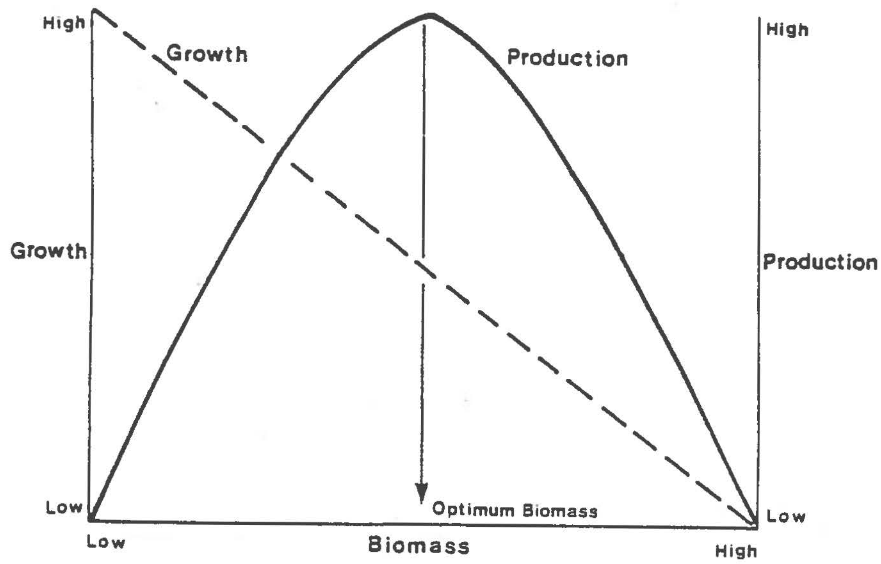

Fig. 2. Theoretical relationship between production and biomass. Modified from Brocksen et al. 1970).

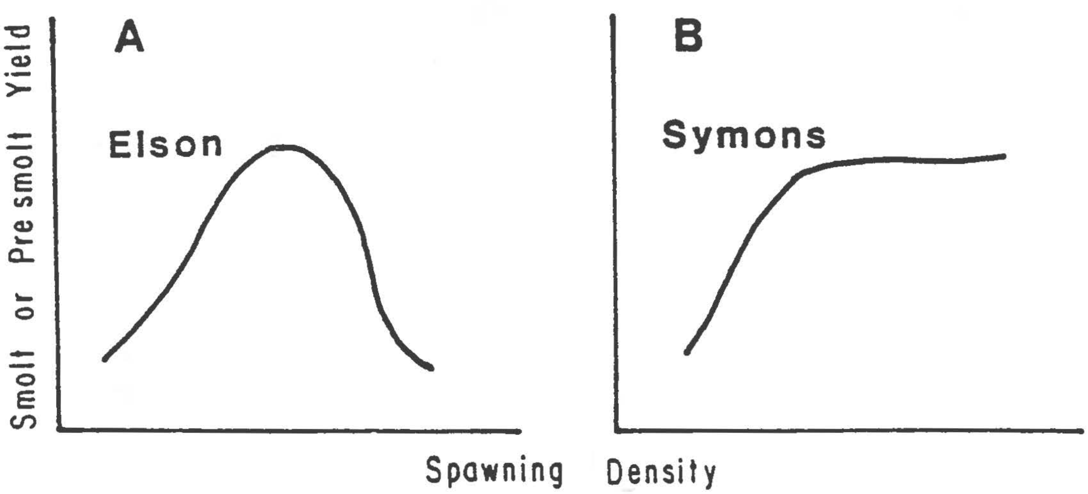

Fig. 3. Relationship between adult salmon spawning density and resulting smolt yield as suggested by Elson (A) and Symons (B). References are given in text. (From Randall 1981).

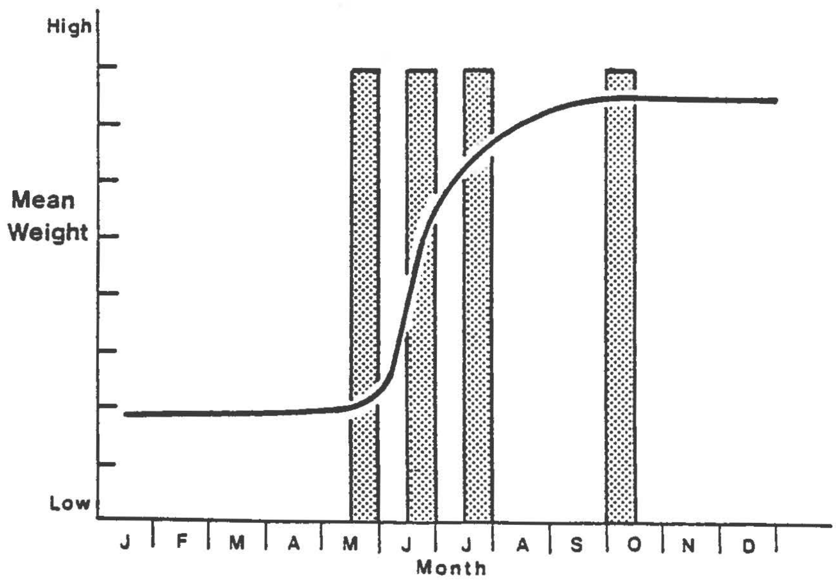

Fig. 4. Generalized seasonal growth curve for juvenile salmon in the Miramichi River. Stipled bars indicate optimum sampling times to estimate production.