Temporal Changes in Body Length, Weight and Fecundity of Coho Salmon (*Oncorhynchus kisutch*) from the University of Washington Hatchery, Puget Sound

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Abstract

Pacific salmon populations in the Puget Sound basin have been affected by changes in freshwater habitat, marine ecosystems, and by decades of culture in hatcheries. These complex factors make it difficult to ascribe declines in salmon abundance or other traits to one cause or another. Nevertheless, long-term records of life history traits can help us detect patterns and infer processes. This paper presents data on coho salmon from the University of Washington's hatchery in the Lake Washington basin. Since the late 1950s, adult coho salmon have become shorter, from over 600 mm fork length to less than 500 mm (range of annual means: 661 in 1965 to 468 in 1997). In addition, the weight at a standard length (545 mm, the long-term mean) has decreased to 1.75 kg, with the decline most evident since about 1980. Overall mean weight has decreased by half, from about 3 to 1.5 kg. As body size declined, the fish have tended to conserve egg size at a cost to fecundity, which is now lower on an absolute basis and lower relative to body size than in the past. Such reductions in fecundity by wild salmon would imply much less productive populations at decreased body size.

Introduction

The declines in abundance of Pacific salmon in the northwest and the application of the United States Endangered Species Act to evolutionarily significant units (ESUs) within species have greatly increased the need to fully understand the status and trends of species and populations in the region over the past decades. It is generally acknowledged that there were periods in the century when salmon were scarce in Alaska, relative to present levels, and at the same time populations in the Pacific Northwest were comparatively abundant. Climatic and oceanographic conditions seem to have shifted in the late 1970s and since that time there have been relatively weaker runs in the Pacific Northwest and stronger runs in Alaska and northern British Columbia (Hare and others 1999).

In addition to changes in abundance, changes in body size have been documented in many salmon populations, and most have shown declines (Bigler and others 1996), including coho salmon in Washington (Weitkamp and others 1995). Size at maturity or growth rate at sea has a genetic component (e.g., Hershberger and others 1990) but it also seems to be affected by both density (i.e., competition: Rogers and Ruggerone 1993) and environmental conditions, notably temperature or some correlate of it (Pyper and Peterman 1999). Finally, selective fishing and both genetic and phenotypic effects from hatchery practices may also play a role (Ricker 1980). Such reductions in size may be accompanied by reductions in fecundity (which would obviously affect productivity), and egg size (which might affect the survival of offspring after emergence). In general, large females produce more eggs and larger eggs than smaller females but females that grow rapidly tend to have a larger number of smaller eggs for given length than females that grew slower (Donaldson and Menasveta 1961).

Thus there are complex combinations of environmental and genetic factors affecting a series of key life history traits in salmonids: growth, age at maturity, and egg production. All of these traits can be affected, directly or indirectly, by artificial propagation of salmonids in hatcheries. This extended abstract reports preliminary results of a study to investigate changes in body size, reproductive output (egg size and fecundity), and the incidence of precocious maturity in the University of Washington's hatchery population of coho salmon since the 1950s to provide insights into the ecology of Puget Sound salmon.

Methods and Materials

Dr. Lauren Donaldson conceived and constructed a salmon and trout hatchery on the UW campus, and the first chinook salmon were released in 1949 (Donaldson 1970; Hines 1976). Coho experiments in the early years were not very successful, but starting in the late 1960s there were substantial numbers of coho salmon returning, along with the chinook. The coho salmon were primarily from the Green River system (Soos Creek hatchery), though some exchange with other populations took place over the years. All returning salmon have been identified, measured for fork length, weighed, and the date was recorded, along with any marks or unusual circumstances. Fecundity and egg size were also estimated volumetrically for many of the females (Allen 1958). The UW hatchery's main water source is the Lake Washington Ship Canal, which drains the epilimnion of Lake Washington. Consequently, it is too warm in the summer to rear Pacific salmon. To accommodate this feature of the site, the coho salmon are reared on an accelerated regime of temperature and food to reach a suitable size for smolt transformation in their first spring of life (Brannon and others 1982). We combined data from hand-written records from 1953 through the late 1980s, and data that had already been entered digitally since then. Our goal was to test the null hypothesis that length, weight and egg productive have remained the same against the predicted alternative hypothesis that body size is declining. In addition to looking at trends in length and overall weight and egg production, we also examined the allometric relationships between length and these traits. To do this, we characterized the relationship between length and the trait being examined for each sex in each year, and standardized the measurement for the overall (long-term) mean length of the population (545 mm). Finally, we examined the incidence of precocious maturity ("jacks") in the male coho salmon.

Results

Male and female coho salmon have declined in length and weight over time. Annual average length has ranged 193 mm, from 661 mm in 1965 to 468 mm in 1997. Annual average weight ranged 2.31 kg, from 3.52 kg in 1973 1.21 kg in 1992. There are two age groups of males (age-1 and age-2). The declines in length and weight were seen in both age groups but were more dramatic in the older fish. The highest average length for male coho at age-2 was in 1973 at 658 mm and the lowest was in 1993 at 431 mm, a difference of 227 mm. The highest average weight for age-2 male coho was at 2.51 kg in 1975 and the lowest was 0.86 kg in 1992, a difference of 1.65 kg. In the early years (1957-1970's) the condition factor (weight at a standard length) was high but it declined through the 1980's and 1990's. Thus the coho salmon have been getting progressively shorter over the whole period or record and also thinner for their length over about the last 20 years.

Fecundity of coho salmon has declined. This was expected, given the reduction in length and weight over time. For example, in 1973 the average length of female coho was 657 mm, weight was at 3.52 kg, and fecundity was 3799 eggs, whereas in 1993 the average length was 475 mm, weight was 1.25 kg, and fecundity was 1351 eggs, a difference of 222 mm, 2.27 kg, and 2448 eggs. After adjustment to a standard length of 545 mm, fecundity still showed a decline. For example, in 1978 the adjusted fecundity was 2949 eggs whereas in 1992 it was only 1771 egg, a difference of 1178 eggs. It appears that in the earlier years (1957 through 1970), weight and fecundity were low, increased during the 1970s but declined over the past 15 to 20 years. In contrast to fecundity, average egg size has remained roughly the same despite declines in body size, and egg size at a standard length has been increasing recently.

The incidence of precocious maturity in male coho salmon ("jacks") has increased over the years at the UW hatchery. The coho jacks are only one year old, having spent only a summer at sea after release. They have been recorded since the first few years of the hatchery operation but were scarce. 1980 marked the first year where a very large number of precocious males (300) returned to the ponds at UW hatchery, and the incidence reached an all time high of 546 in 1985. The proportion of jacks in the total number of males returning has been on the order of 10-20% but reached 49.5% in 1985. The large number of jacks seemed to coincide with the periods of greater decline in length, weight, and condition of the returning coho salmon.

Discussion

The decline in body size (length and weight) evident in the UW coho population has been shown in other species throughout the Pacific Northwestern (Bigler and others 1996; Pyper and Peterman 1999) but weight and length are seldom recorded on the same fish so our data on condition factor are especially valuable. Recent evidence suggests that competition for food and ocean conditions (e.g., sea-surface temperatures) may contribute to temporal variation in adult body size. Pyper and Peterman (1999) indicated that increases in total sockeye abundance and sea-surface temperatures were major factors in the reduction of adult body length, and abundance appeared to have a greater effect on body length than temperature. High production levels of salmon at hatcheries, including the University of Washington, may explain some of the decline in size through competition. However, Knudsen and Busack (this symposium) presented evidence for the role of size-selective fisheries in patterns of decline coho salmon body size among populations. The UW population is subjected to a variety of fisheries, including gillnets which are size-selective. Further investigation will be need but it may prove difficult to disentangle the effects of several factors (ocean conditions, fisheries, hatchery practices and competition) acting over the same time period. Whatever the cause, such declines in size might compromise the viability of wild populations.

The absolute fecundity declined along with length, but the decline accelerated over the last 20 years, when condition factor has also declined. The salmon generally allocate a percentage of their weight to eggs and so salmon that are both shorter and thinner produce far fewer eggs than longer and more robust fish. Such declines in egg production, if seen in wild populations, would indicate serious reductions in reproductive potential. In contrast, egg size seems to be stable, as though there is some minimal size of egg and offspring. This phenomenon may be explained in part by the fact that rapid growth is associated with a high fecundity for a given length in salmon. Egg size is also affected because salmon adjust egg size to accommodate egg number, given the energetic constraints of gonad production. UW coho are expressing the results of poor growth with fewer but larger eggs for a given body length.

Accelerated incubation and rearing of coho can result in the production of precocious spawners or age-1 jacks, returning after only 5 to 6 months of marine residence, and Brannon and others (1982) reported that brood years with larger smolts produced more jacks. This hypothesized relationship between smolt size and proportion of jacks will be tested in the future with the additional decades of data. We will also examine possible interactions between size and release date of smolts on precocious maturity. It is interesting to note that the prevalence of jacks does not result from but rather runs counter to genetic selection, as jacks are not used for spawning. Therefore, the accelerated incubation and growth at the hatchery is the best explanation for the high number of returns of coho jacks. Paradoxically, the proportion of jacks has been high during the same period that adult size at age has declined, suggesting opposing effects of growth in the hatchery and at sea.

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