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Enhancement Effects of Spawning Pink Salmon on Stream Rearing Juvenile Coho Salmon: Managing One Resource to Benefit Another

Abstract

This paper examines the relationship between the number and biomass of pink salmon spawning in the Skagit River and the resulting return of adult coho salmon which were rearing as age-0 fish in the watershed at the time of spawning. From 1967 through 1985, during the odd-numbered years, there is a strong direct correlation between the biomass of pink salmon spawners present in the Skagit River and recruit per spawner for coho salmon present in the system as age-0 fish at the time of pink salmon spawning. Moderate flows, or at least the lack of large freshets in October, increase the benefit that pink carcasses provide. Further, the streamflow in summer shows a strong positive influence on recruit per spawner for coho salmon. Traditional salmon management has concentrated on one species at a time. In order to take advantage of the enhancement benefit conferred by pink salmon spawners it will be necessary to examine interspecies impacts, reduced consumptive fisheries, changes in land use activities, and changes in stream flows from a much broader perspective than is presently employed.

Introduction

Anadromous salmonids native to the Pacific coast of North America, such as Pacific salmon, trout, and char are known for their intriguing life cycles. Adults spawn in gravel of freshwater lakes and streams. Depending on species, emerging young either migrate to saltwater within a short period of time (days or weeks) or spend up to four years in freshwater before migrating to saltwater (Groot and Margolis 1991). After one to six years at sea, adults return to their natal stream to spawn. Pacific salmon (*Oncorhynchus* spp.), are semelparous and die after spawning, whereas Pacific trout (formerly *Salmo* but now classified as *Oncorhynchus*) and char (*Salvelinus*) may be iteroparous and generally survive at least one spawning migration (Scott and Crossman 1973). Depending on species, juveniles will weigh between 0.13 grams (g) and 35g when they migrate to the ocean. The range in weight for returning adults, again depending on species, is between 0.5 kilogram (kg) and 45 kg (Groot and Margolis 1991).

Recently, attention has been focused on the declines of wild salmon populations in the Pacific Northwest (Nehlsen, et al. 1991; Palmisano, et al. 1993; Wissmar, et al. 1994 ; and McIntosh et al. 1994). Historically, the rivers and streams along the Pacific coast of North America supported vast numbers of spawning salmon. For example, the Fraser River in British Columbia produced sockeye salmon (*Oncorhynchus nerka*) runs of between 30 and 40 million fish (Roos 1991, Gilhousen 1992). Ricker (1987) estimated some individual spawning streams in the Fraser River watershed may have had as many as 1 million spawning sockeye per kilometre (km) of river. Even today, some rivers such as the Fraser continue to have spawning escapements in the millions of fish (Roos 1991).

Large spawning aggregations of salmon transport significant amounts of nutrients from marine waters to freshwater systems. Kline et al. (1990), using isotopes of marine origin, documented that salmon carcasses provided a significant amount of the nutrients which "fed" streamlife. Richey et al. (1975) demonstrated that peaks of nutrient levels, carbon fixation, and periphyton biomass occurred following spawning and death of resident sockeye salmon (kokanee) in a stream. Koenings and Burkett (1987) suggested that fewer spawners, resulting in reductions in nutrient input, may be partially responsible for the inability of the sockeye salmon population to increase to historic levels in Karluk Lake, Alaska.

Salmon management has traditionally focused on a single species at a time. In this paper, the relationship among the numbers and biomass of spawning pink salmon (*O. gorbuscha*) and the numbers of adult coho salmon (*O. kisutch*) returning two years later was examined. The Skagit River system was chosen because the number of spawning pink salmon is relatively large when compared to other salmon species in the system (hundreds of thousands versus tens of thousands) and the Skagit River coho salmon stock has been critical to fishery management in Washington State in recent years due to its generally low level of abundance throughout its migratory range. The argument is developed that management schemes which consider interspecies effects may be more beneficial to overall fish production from a given watershed, especially when the overall ecosystem impacts are considered. Also discussed are the impacts that management of terrestrial resources (such as land and timber management) may have on fish production and vice versa.

Pink salmon are the most abundant and smallest bodied Pacific salmon species (Heard 1991). In their native range, pink salmon have a fixed two-year life cycle. Skagit River pink salmon spawn in odd-numbered years, normally in September and October. Most of the spawning occurs in the mainstems of the Skagit River and its major tributaries. Following emergence from the gravel, the fry immediately migrate downstream to saltwater.

Coho salmon have a longer and more complex life cycle than do pink salmon; they typically live in fresh water for one or two years prior to their migration to the ocean as smolts. This migration typically occurs in the spring with peak movement occurring in May. Mature coho salmon return to fresh water to spawn after spending (approximately) six or eighteen months at sea (Sandercock 1991). In the Skagit River watershed most coho spawning occurs in small tributary streams.

Study Area and Methods

Although the headwaters of the Skagit River are in Canada, most of the drainage basin is located in the northwest portion of Washington State. The mainstem Skagit River, upstream from river km 144, has a series of hydroelectric dams which are blockages to upstream fish migration.

The number of fish (run size), number of spawners (escapement), and average weights used in the analyses came from Washington Department of Fish and Wildlife (WDFW) files. The total run sizes for Skagit River origin coho salmon and pink salmon are the estimated numbers of spawners plus an estimate of catch taken by commercial net fisheries in Puget Sound. WDFW assumed the number of salmon calculated in the estimates of run sizes consistently reflected stock abundance (Washington Dept. of Fisheries 1984).

The escapement estimates for both species of salmon were based on visual counts of live and dead fish in selected sections of spawning streams (index areas). Surveys are conducted on a regular schedule, water conditions permitting, during the spawning seasons. The counts from the index areas are expanded based on relationships developed in "base years" between the index counts and total system escapement (G. Zillges and J. Ames, WDFW biologists, pers. comm.).

Recruit per spawner (R/S) is defined as the number of returning adult fish (recruits) produced from a given number of spawners. An R/S less than 1.00 means each parent produced less than one surviving offspring. Ultimately, this rate of reproduction leads to extinction. Conversely, an R/S greater than 1.00 means each parent produced more than one surviving offspring. For fish resources managed for consumptive harvest, recruits in excess of the desired number of spawners are available for harvest.

Total biomass of pink salmon carcasses per year was calculated by multiplying the number of spawning pink salmon by the mean weight of pink salmon caught in Puget Sound at Skagit Bay and in the Skagit River by commercial fishermen. In order to account for differential availability of salmon carcasses due to stream flows (per Hunt et al. 1992) the biomass of pink salmon carcasses was adjusted by multiplying the carcass biomass by the inverse ratio of flow in October (mean or peak) in that year to the overall mean flow (mean or peak) for all years. The effect of this adjustment is to increase the "carcass biomass" in years of lower than average flows and decrease it for years when flows were greater than the mean.

The Puget Sound Index (PSI) is a measure of summer low flows from a representative group of streams which discharge into Puget Sound. Low stream flows are often used to predict adult coho salmon abundance because of the inverse relationship between summer flow levels during juvenile rearing and adult coho returns (Mathews and Olson 1980). Streamflow data are taken from United States Geological Survey files.

Pink salmon spawning escapement, carcass biomass (including adjusted biomass), coho spawning escapement, PSI, and Skagit River flows in

October were regressed against coho R/S. Variables were regressed singly and in stepwise fashion to determine correlations.

Results and Discussion

During odd-numbered years between 1967 and 1985, WDFW estimated that between 100,000 and 710,000 pink salmon spawned per year in the Skagit River, resulting in carcass deposition of an estimated 213,000 to 1,642,000 kg (Table 1). The R/S for coho rearing in the system at the time of pink spawning during these years ranged between 0.677 and 3.479, with higher R/S values associated with the larger pink salmon escapements (Table 1).

There is a positive correlation between biomass of pink salmon carcasses and coho salmon R/S. Biomass of pink salmon carcasses indexed to reflect peak and mean October flows showed strong correlations (r^2=.762, p<.001 and r^2=.656, p=.005, respectively) with coho R/S salmon (Table 2). Coho salmon recruit per spawner was also significantly correlated with coho spawning escapement and the peak river flow in October (r^2=.428, p=.040 and r^2=.402, p=.049, respectively) (Table 2). Stepwise regression utilizing all variables regressed against coho salmon R/S added the PSI to pink salmon biomass indexed for peak October flow. The resulting regression with coho salmon R/S increased the r^2 to 0.895 and p<=.001 (Table 2).

Return of adult coho salmon, expressed as a ratio of returning adults to numbers of spawners, shows a strong positive correlation with the biomass of pink salmon which spawned while the coho salmon juveniles were rearing in the river. As the amount of pink salmon carcass biomass entrained in the Skagit River system increased, the number of coho salmon adults per spawner increased. It was assumed that pink salmon carcass entrainment was inversely correlated with streamflow; this was supported by the increased correlations when carcass biomass was indexed to reflect October flow conditions. Summer low flow, as measured by the PSI, shows a direct relationship between adult coho produced from the Skagit River system with lower summer flows resulting in fewer adult fish.

Based on the correlations calculated in this study, observations of other streams, and a review of the literature, I offer the following as the enhancement mechanism.

During spawning, pink salmon disturb large areas of stream bottom. The more spawners that are present, the greater the disturbed area. Physical disturbance displaces the insects living on the bottom and causes them to drift downstream where they can be eaten by fish. Field-Dodgson (1987)

TABLE 1. Pink salmon and coho salmon run size and carcass biomass and Skagit River flows, 1967-1985.

	Pink		Coho			*Skagit River Flow		Adjusted Carcass Biomass	
Year	Escapement Number	Kilogrammes (kg)	Escapement Number	R/S	Puget Sound Index	Peak cms	Mean cms	Peak Flow (kg)	Mean Flow (kg)
1967	100000	235000	25500	0.677	6.602	1755	351	123000	197000
1969	100000	254000	21000	1.244	8.477	733	378	318000	197000
1971	300000	694000	21800	1.240	9.370	521	250	1222000	816000
1973	250000	624000	19800	1.263	6.512	708	249	808000	735000
1975	100000	1290000	31800	1.400	12.274	1480	170	180000	501000
1977	500000	1338000	16000	3.442	8.385	357	198	3440000	1982000
1979	300000	680000	14100	1.521	6.610	614	230	1015000	870000
1981	100000	213000	25500	1.375	8.821	931	408	210000	153000
1983	470000	938000	9000	3.479	12.765	422	218	2039000	1266000
1985	710000	1642000	35600	1.169	7.513	1647	485	914000	994000
Mean	293000	690800	22010	1.681	8.733	917	294	1026900	771100

*Data from site 1200500, near Mt. Vernon, Washington

TABLE 2. Single and stepwise regression analyses for selected variables.

Variables	df	r-sq	F-value	p
Single regressions				
pink kg-adj peak	8	0.762	25.55	<<0.001
pink kg-adj mean	8	0.656	15.26	0.005
coho escapement	8	0.428	5.99	0.040
peak flow	8	0.402	5.38	0.049
mean flow	8	0.246	2.60	0.145
Puget Sound Index (PSI)	8	0.239	2.52	0.151
pink escapement	8	0.229	2.38	0.162
pink kilogrammes	8	0.227	2.35	0.164
Stepwise regression				
adj kg-peak, PSI	7	0.895	29.84	<<0.001

documented that spawning chinook salmon (*O. tsawytscha*) were able to depopulate a stream of its insect population. Further, the level of depopulation was directly related to the number of spawners. Spawners also dig up previously spawned eggs making them available to fish. Following spawning, the salmon die. Coho juveniles are then able to feed on the decomposing carcasses (R. Bilby, Weyerhaeuser Aquatic Ecologist, pers. comm.).

As the carcasses decompose, they are incorporated into the stream food web (R. Bilby, Weyerhaeuser Aquatic Ecologist, pers. comm.). The captured energy is then cycled through the system and becomes available to the coho, primarily as insects. Many of the carcasses are hauled out of the stream onto land for consumption by terrestrial animals and subsequent nutrient cycling through the terrestrial ecosystem (Cederholm, et al. 1989). Some of the energy captured in the terrestrial systems may return to the river and be added to the food resources available to coho. Johnston et al. (1990) showed applications of fertilizer to a coastal river in British Columbia substantially increased the average weight of juvenile salmonids. Andersen et al. (1992) showed growth rates for age 0 brown trout (*S. trutta*) were directly related to food resources available to the fish. The fish in the stream with the greatest food supply were both faster growing and larger at the end of the experiments. Other studies have documented survival to adulthood for coho salmon smolts increases with increasing size of out-migrant (Holtby et al. 1990). Bilby and Bisson (1992) believe increasing nutrients in streams might be beneficial to juvenile anadromous fish production by increasing the amount of food available.

Increasing the biomass of pink salmon carcasses entrained in the Skagit River system can be accomplished in a number of ways, including allowing more pinks to spawn, utilizing dams to have better control of both maximum and minimum flows, or increasing the ability of the river to trap and hold the carcasses. These, as well as other options, can be combined into a holistic package of management options for the system.

Increasing the numbers of pink salmon spawning in the Skagit River, however, may have a negative impact on the production of chum salmon. Ames (1983) estimated that an increase in Puget Sound pink salmon spawning escapement from 300,000 to 900,000 would reduce R/S for all Puget Sound chum salmon from 3.25 to 1.45. He surmised that there was competition for food between pink and chum salmon fry with the pink salmon being able to outcompete the chum salmon. The interactions between chum, coho, and pink salmon and the impact of escapement changes on other species of salmonids which rear in the Skagit system, such as chinook salmon, steelhead trout (*O. mykiss*), cutthroat trout (*O. clarki*), Dolly Varden (*S. malma*), and bull trout (*S. confluentus*), may also reveal similar interconnections.

In addition to the potential loss of chum salmon production, an increase of pink salmon escapement in the Skagit River could require at least a short-term reduction of harvest of Skagit River pink salmon in years of low runsize. The reduction in catch would primarily affect the commercial net fishermen operating in Skagit Bay and the Skagit River. The loss in catch would reduce their incomes. The benefits in coho salmon production would generally accrue to the marine hook and line fleets, although an increase in coho abundance would provide additional harvest by bay and river fishermen. Also, the coho salmon hook and line and the pink salmon net fisheries are generally geographically separate, so different communities would benefit.

Entrainment of salmon carcasses requires that there be a certain level of complexity in the stream environment. Recent studies have shown that habitat complexity, as measured by the amount of debris and rock in a channel, increases the ability of a stream to retain and cycle nutrients (Cederholm and Peterson 1985, Sedell et al. 1988, Dobson et al. 1992, Garman et al. 1992). Growns and Davis (1991) showed that eight years after logging there were still significant differences in the invertebrate communities between clearcut and unlogged areas. They further found that invertebrate communities in a stream which had been protected by a 100 m-wide buffer strip had a different community structure than that found in the unlogged streams. But the communities in the stream protected by the buffers were more similar to the unlogged streams than to streams in the clearcut areas. By retaining or enhancing a stream's ability to capture, retain, and cycle nutrients more energy will be present in the system and available to the fish living there.

An objective evaluation of any change in resource management, such as increasing the pink salmon escapement to increase adult coho salmon return is difficult. While the value of a resource which has a commercial market value is relatively easy to calculate, it is difficult to calculate the "value" of a resource which has recreational harvest values, recreational non-harvest values, "spiritual" values, and ecosystem values independent of commercial harvest. The problem becomes even more complex when land use questions, growth management issues, and industries such as logging and agriculture must be considered.

The problem becomes even further exacerbated by a political system which views planning as "what will we do tomorrow?" and long range planning as "the next budget cycle." The research necessary to actually understand the interrelationships of the components of an ecosystem is expensive and time-consuming. Anyone familiar with the fiscal climate in recent years knows that government finds it difficult to address future benefits. Consequently, we deal with today's problems today and tomorrow's problems at some other time.

Summary

There is a strong direct correlation between the biomass of pink salmon spawners present in the Skagit River and recruit per spawner for coho salmon present in the system as age-0 fish at the time of pink salmon spawning. It appears that moderate flows, or at least the lack of large freshets in October, increase the benefit that pink carcasses provide. Further, the streamflow in summer shows a strong positive influence on recruit per spawner for coho salmon.

Based on the relationship between pink salmon and coho salmon, and the potential for interactions with other salmonid species, it is obvious that decisions regarding spawner escapement levels for one species need to consider the impacts on, and interactions with, other species. There may be instances when it is more valuable to long term productivity of an ecosystem and overall societal economic benefit to forego catch of one species in order to increase the abundance of another. There is a need to further study the relationship between nutrient level in streams and resultant fish populations. Finally, the relationships between fish production and development in a basin needs to be evaluated so resource management and utilization decisions can be made which will integrate the entire ecosystem rather than isolate each piece with decisions made in a vacuum.

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