John H. Michael Jr., Washington Department of Fish and Wildlife, 600 Capitol Way N, Olympia, Washington 98501-1091

Pacific Salmon Spawner Escapement Goals for the Skagit River Watershed as Determined by Nutrient Cycling Considerations

Abstract

Wild populations of Pacific salmon (*Oncorhynchus spp.*) in Washington State are generally at low levels compared to populations that were likely present before the arrival of Euro-Americans in the Pacific Northwest. Habitat loss, the introduction of non-native stocks and species, and overfishing have all contributed to the decline. Historically, huge numbers of salmonid carcasses provided entire watersheds with nutrients derived from the ocean. Diminished populations and transport of these nutrients out of watersheds has caused a nutrient deficiency compared to times when populations were large. This nutrient deficiency may be hampering recovery of salmon and other animal populations. Beginning with the premise that the Pacific Northwest ecosystem evolved to fully utilize massive numbers of spawning salmon, I estimated the biomass of salmon carcasses necessary to support nesting song birds, wintering bald eagles, and salmonid smolt production in the Skagit River watershed in Washington. The proposed spawner escapement goals thus estimated are 150% to 680% higher than current spawner escapement goals for salmon in the watershed. The justifications for these proposed goals include comparison with escapement goals used in other watersheds, the actual uptake of marine-derived nutrients by fish, the impact of increased escapement on subsequent smolt production, and actual relationships between adult spawners and smolts in less intensively fished streams. Actual attainment of these goals will need to consider the physical condition of the watershed and its ability to retain and cycle the nutrients and the social and economic disruption to fisheries that may result from allowing more fish to survive to adulthood and spawn.

Introduction

Declines of wild salmonid populations in the Pacific Northwest have focused attention on the region, its fish populations, and changes in aquatic and terrestrial habitat which threaten the continued existence of large anadromous salmonid populations (Nehlsen et al. 1991, Palmisano et al. 1993, McIntosh et al. 1994, Wissmar et al. 1994). The ecosystem in which Pacific salmon (*Oncorhynchus spp.*) evolved was one where they transported substantial amounts of nutrients from marine to fresh water when they returned to their natal watershed to spawn and die. Kline et al. (1990) and Kline et al. (1993), using isotopes of carbon and nitrogen, documented that salmon carcasses provided nutrients which "fed" stream and lake ecosystems. At Karluk Lake, Alaska, Koenings and Burkett (1987) suggested that reduced nutrient input resulting from fewer spawners contributed to the inability of the sockeye salmon population to increase to historic levels. Other studies have shown that the addition of nutrients to aquatic systems increased juvenile salmon size and increased the abundance of adults (Holtby et al. 1990, Johnston et al. (1990), Kyle (1994), and Stockner and MacIsaac (1996).

Before commercial canneries, with their product distribution networks which transport preserved salmon flesh far from the home watershed, most of the salmon biomass harvested by animals or people remained in the watershed. Waste was generally returned to the river, the animals and people lived and died in the watershed, and so on. Consequently, it seems reasonable that the watersheds of the Pacific Northwest evolved to capture and use the massive annual influx of marine nutrients brought by anadromous salmonids.

Salmon carcasses are utilized at every level of the food chain, and then cycle through the system by consumption as prey items (Bilby et al. 1996). Willson and Halupka (1995) hypothesized that anadromous fish in Pacific Northwest streams are keystone animals of the ecosystem. Salmonid presence and abundance has important consequences for the distribution and abundance of terrestrial vertebrates. Sibatani (1996) presented the idea that one major ecological role of Pacific salmon is to transport nutrients, particularly phosphates and nitrates, from the ocean to the forest lands surrounding the northern Pacific Ocean range of the fish. He used calculations which showed that riparian forest birds incorporate a significant portion of nutrients from salmon carcasses by eating insects which had fed on the carcasses. Hilderbrand et al. (1996) calculated that 33% to 90% of the metabolized carbon and nitrogen in museum specimens of Columbia River drainage grizzly bears (*Ursus arctos horribilis*) collected before dam construction was obtained from salmon. Ben-David et al. (1997) concluded that mink (*Mustela vison*) in southeast Alaska relied on salmon carcasses as a food source during the autumn spawning runs. Hunt et al. (1992) and Stalmaster and Kaiser (1997) estimated the amount of salmon carcasses consumed by bald eagles (*Haliaeetus leucocephalus*) wintering on western Washington rivers. Both papers noted that overall numbers of wintering bald eagles were directly related to actual availability of salmon carcasses. These studies allow for a quantification of salmonid carcasses needed within an ecosystem. Cederholm et al. (1989) documented a wide variety of terrestrial mammals and birds that feed on salmon carcasses, but did not quantify the amount of usage.

Michael (1995) demonstrated a direct correlation between the biomass of spawning pink salmon (*O. gorbuscha*) and the resultant production of adult coho salmon in the Skagit River. Ongoing studies by the Washington Department of Fish and Wildlife (WDFW) have further supported this relationship by showing that coho salmon smolt production in the Skagit River was strongly and directly correlated to the number of pink salmon spawning the year before smolt emigration (D. Seiler, WDFW Biologist, pers. comm.). Therefore, relating the biomass of smolts produced in a system to the biomass of carcasses necessary to produce them could provide an escapement goal which considers the "needs" of the ecosystem across species rather than the traditional single species spawner-recruit models.

To effectively manage any renewable resource, it is necessary to define and protect a specified level of reproducing individuals—the escapement goal in fisheries. This level of reproduction is also used to measure the success of a management strategy. Presently, most fish management strategies for Washington salmon stocks maximize the production of harvestable fish. Increasing the escapement goals will, at least in the short term, lower harvest levels, and stakeholders generally oppose attempts to reduce harvests without justification. Larkin and Slaney (1997) reviewed salmonid escapements and resultant fish production in British Columbia, and concluded (pg. 22) "... enough information has been gathered ... to conclude that wild stocks may be at risk and, therefore, we argue for an immediate management response". WDFW is developing a new set of policies to manage wild salmonids. Among the goals of these policies will be increased spawner escapements. Current spawner escapements are based on some variant of Maximum Sustained Yield with considerations of economics and other non-biological aspects as desired by the managers (Wright 1981). Presently, the escapement goal does not consider the nutrient contribution of adult spawners to the ecosystem.

The goal of this paper is to present a method for determining the spawner escapement goal for Pacific salmon by attempting to quantify the number and biomass of salmon carcasses required to support nutrient needs of specific segments of the ecosystem. The Skagit River watershed was used as an example to test how the method might affect spawner escapement goals. The first step was to calculate the amount of food necessary to: (1) produce a given biomass of juveniles of selected anadromous salmonids with extended freshwater rearing, (2) support overwintering bald eagles, and (3) support nesting insectivorous birds. The estimated spawner biomass was then compared with recent levels of spawner biomass observed in the Skagit River. Spawner escapement goals developed using this method offer a scientific basis for increasing spawner levels but they underestimate actual ecosystem needs because they exclude species such cutthroat trout (*O. clarki clarki*), native char (*Salvelinus spp.*), sturgeon (Acipenseridae), lampreys (Pteromyzontidae), and smelt (Osmeridae) for which little information on numbers and biomass of spawners exists. Estimates also do not include quantities of marine-derived nutrients needed by herptiles, mammals, birds other than the riparian zone nesters and wintering bald eagles, insect-consuming invertebrates, or plants.

Study Area and Methods

This study is based on the Skagit River watershed in Washington, USA. Michael (1995) describes the Skagit River watershed and salmon populations and biomasses. An estimated 905.4 km of stream are accessible to anadromous fish in the Skagit River watershed (Johnson 1986).

Spawner escapement goals which recognize ecosystem nutrient needs can be expressed as:

$$\Sigma B = B_1 + B_2 + B_3 + \ldots B_n$$

Where:

ΣB= the total biomass of salmonid carcasses necessary to supply nutrients to the ecosystem

B_1= carcass biomass necessary to support chinook salmon (*O. tsawytscha*), coho salmon (*O. kisutch*), and steelhead trout (*O. mykiss*) smolts

B_2= carcass biomass necessary to support nesting insectivorous birds

B_3= carcass biomass necessary to support wintering bald eagles

B_n= carcass biomass necessary to support other parts of the ecosystem such as bears, mink, herptiles, waterfowl, other fish, plants, etc.

The biomass must then be converted to numbers of spawners so that individual runs of fish can be managed.

Carcass Biomass to Support Salmonid Smolts (B_1)

For ease of calculation, it was assumed that salmonid smolts only consumed invertebrates (mostly insects) in freshwater. In the Skagit River watershed, estimates are available for the smolt production for chinook and coho salmons and steelhead trout; all have extended rearing in the watershed. At present, estimates of the number of cutthroat trout and native char are not available. Inclusion of cutthroat and char would increase the estimate of carcass biomass necessary to support salmonid smolts. Estimates of smolt production for those species that make extensive use of the freshwater environment for rearing were developed from actual trapping data or calculations based on available habitat or average survivals. Tweit (WDFW biologist, pers. comm.) estimated that 4,296,000 chinook salmon smolts are produced under average environmental conditions when current escapement goal was met. Actual trapping on the Skagit River estimated that 1,100,000 coho salmon smolts are produced (D. Seiler, WDFW biologist, pers. comm.). This number is less than the smolt production potential of 1,453,878 estimated by Zillges (1977) and substantially less than the smolt production potential of 2,146,701 estimated by Johnson (1986) but represents the current situation in the watershed.

No estimates of actual smolt potential for steelhead trout in the Skagit system are available, so WDFW based the escapement goal on the number of parr (372,672) rearing in the stream during the summer before smolting (Northwest Indian Fisheries Commission et al. 1985). For each species, the biomass of smolts or parr was estimated by using 7g for chinook salmon, 14g for coho salmon and 20g for steelhead trout, which represented mean individual fish weights observed in western Washington (WDFW files). Assuming that the fish consume only insects, a conversion factor of 4.0 (Piper et al. 1986) was used to convert the smolt/parr biomass to the insect biomass required by the smolts or parr.

Carcass Biomass Needs for Nesting Insectivorous Birds (B_2)

In his discussion of the transport of marine nutrients to upland areas, Sibatani (1996) estimated that nesting birds in the Shiga Highlands, a conifer forest in Japan, consumed 10,000 kg of insects per km^2 of forest from May to October. This estimate was used to apply to the riparian forests of the Skagit River watershed because a local estimate could be located. Sibatani (1996) recognized that organic matter is lost through energy metabolism but that (pg. 7) " ... a cycle of inorganic elements whose weight is always conserved, there seems to be no problem in representing this weight with the live weight of insects and birds." Consequently, a direct conversion of carcass weight to insect weight was used to estimate the biomass of carcasses necessary to produce the insects for nesting birds. To apply this to the Skagit River watershed, a width of 100 m on each side of the stream in the anadromous zone (905.4 km) was assumed to be most directly affected by the carcasses and the 10,000 kg/km^2 was applied to that area.

Carcass Biomass for Overwintering Bald Eagles (B_3)

Stalmaster and Gessaman (1984) estimated that a bald eagle wintering along the Skagit River requires 486 g of salmon flesh per day. Hunt et al. (1992) estimated Skagit River wintering eagle populations from 1973-81. For the winter of 1980-81 they estimated 4,396 kg of salmon was necessary to support the eagles, but this eagle population (1980-81) was only 33.1% of the largest wintering population estimated between 1973 and 1981. Supporting the largest population required 13,284 kg of carcasses.

Converting Biomass to Numbers of Fish in the Escapement Goal

Seiler (WDFW Biologist, pers. comm.) observed that in years when pink salmon spawn in the Skagit River, more than 1 million coho salmon smolts were produced the following spring, while in non-pink salmon spawning years, the average annual smolt production was 650,000 coho salmon. When coupled with Michael's (1996) study of interactions between pink salmon and coho salmon, and the fact that in Washington pink salmon essentially spawned only in the early fall of odd numbered years, and the only other early fall spawning salmon in the system was the chinook salmon, it is assumed that a similar biomass of carcasses was needed in the fall of even numbered years to obtain similar numbers of coho salmon smolts. From Seiler's data, an escapement of 500,000 pink salmon maximized the production of coho salmon smolts under current watershed conditions. Thus, 500,000 was used as the escapement goal for pink salmon. The biomass of 500,000 pink salmon spawners was divided by the mean weight of adult Skagit River chinook salmon to obtain a goal for non-pink years. In the current management scheme, spring chinook salmon comprise 16.8% of the total chinook salmon escapement goal with the remainder being a mixture of summer and fall chinook salmon. The relationship between the two groups of chinook salmon was maintained in the proposed goals.

Conceptually, it might appear appropriate to increase the chinook salmon escapement goal only in even numbered years because of pink salmon presence in odd numbered years. Having different escapement goals for even and odd years is used for chum salmon (*O. keta*). However, consumptive fisheries for chum salmon occur only on maturing fish, while consumptive fisheries for chinook salmon occur over most of the life cycle with a substantial portion of the marine harvest taken as immature fish. In order to have an even year and an odd year escapement goal for chinook salmon and still maintain marine fisheries on immature fish it will be necessary to have some sort of external mark which will identify at what age the fish will mature. This mark currently does not exist. It would be possible to use different escapement goals for chinook salmon if all fisheries were conducted in the river of origin on returning spawners.

Ames (1983), in a discussion of salmon stock interactions in Puget Sound, suggested that increases in total Puget Sound pink salmon spawning escapement would reduce recruit per spawner for Puget Sound chum salmon. He surmised that pink salmon fry would outcompete chum salmon fry for food. To maintain a balance within the Skagit River watershed, the escapement goals for chum salmon were increased by the same proportion as the increase in the pink salmon escapement goal. Chum salmon in Puget Sound show two distinct population sizes. The run sizes and escapement goals in even numbered years are substantially higher than in odd numbered years; this same relationship was maintained in the development of the proposed goals. For coho salmon, the smolt per adult spawner ratio of 15.2 observed over 14 years of trapping at Snow Creek (Johnson and Cooper 1993) was multiplied by the Skagit River coho salmon smolt estimate of 1,100,000 to calculate the required escapement.

Results

The Skagit River watershed, under average environmental conditions and current spawning escapement goals (as defined by WDFW), should require 200,000 kg of salmon carcasses to support smolt production, 13,000 kg of carcasses to support wintering bald eagles, and 1,800,000 kg of carcasses to support insectivorous bird nesting and brood rearing for a total requirement of 2,000,000 kg (Table 1). The spawning escapements in the Skagit River watershed during 1970-1994 were consistently lower than this (Table 2). Even if all salmon species met their present

TABLE 1. Biomass (kg) required for salmonid smolts produced, birds nesting within 100 m of streams, and for wintering bald eagles in the Skagit River watershed.

Consumer	Biomass
Salmonid smolts and parr	205,704
Riparian zone nesting birds	1,810,820
Overwintering bald eagles	13,284
Total	2,029,808

TABLE 2. Natural salmon escapement, in numbers and biomass, to the Skagit River, 1970-1994.

Species	Spawning escapement (N)			Biomass (kg)		
	Goal	Mean	Frequency of Goal Achievement	Maximum	Minimum	At Goal
Chinook						
Spring	3,000	1,509	0.040	26,830	6,149	29,283
Summer/Fall	14,900	12,861	0.320	242,609	57,746	145,439
Total	17,900	14,870	0.320	268,777	65,310	173,746
Coho	30,000	21,884	0.280	130,993	28,060	100,788
Pink	330,000	383,692	0.583	1,643,934	213,380	779,064
Chum						
Even year	117,800	107,407	0.538	931,233	115,528	679,211
Odd year	38,900	28,392	0.333	473,713	27,491	224,289
All species						
Even year						953,745
Odd year						1,277,887

escapement goal, only 45% to 60% of the required biomass (Tables 2 and 3) would be realized. Pink salmon and even-year spawning chum salmon show the best performance, having met or exceeded established goals slightly more than half the time.

To supply approximately 2 million kg of carcasses, salmon escapement goals for the watershed should be increased to 20,400 spring chinook salmon, 101,200 summer and fall chinook salmon, 72,400 coho salmon, 500,000 pink salmon, and 178,500 and 59,000 even and odd year chum salmon, respectively (Table 3). These goals represent substantial increases for chinook and coho salmon but represent levels of escapement occasionally met by chum salmon or regularly met by pink salmon in the Skagit River watershed.

TABLE 3. Proposed spawner escapement goals and potential biomass (kg) for Skagit River chinook salmon, coho salmon, pink salmon, and chum salmon.

Species	Spawning Escapement	
	Number	Biomass
Chinook		
Spring	20,400	198,012
Summer/Fall	101,200	982,296
Total	121,600	1,180,308
Coho	72,400	243,235
Pink	500,000	1,180,400
Chum		
Even year	178,500	1,029,195
Odd year	59,000	340,181
All Species		
Even year		2,452,738
Odd year		2,944,124

Discussion

The estimated biomass of carcasses required to meet wintering eagle, nesting bird, and salmonid smolt production in the Skagit River system is approximately twice the amount currently provided by the spawner escapement goals targeted in the present management scheme. Because the current management framework rarely achieves the escapement goal for any single species, and never achieved the escapement goal for all species in any year from 1970 to 1994, it can be assumed that the current management practices result in a deficit in the return of nutrients to the watershed. Further, because the estimate is a minimum requirement for only a fraction of the consumers of nutrients in the system, it is probable that the system as a whole has a severe nutrient deficit.

Nutrient deficit is probably a coastwide problem. The National Research Council (1996) estimated that 6 to 10% of the historic levels of salmon spawners and associated nutrients are returning to the Willapa Bay Basin, located in southwestern Washington. Historic spawning escapements and total run sizes were difficult to estimate because data is lacking or inconsistent. Most early (late 1800s through mid 1900s) fishery data only reported catch and rarely quantified escapement. Additionally, reports of run sizes (catch plus escapement) sometimes varied widely. For example, Ricker (1987) and Gilhousen (1992) reviewed available data for Fraser River sockeye salmon (*O. nerka*) between 1890 and 1920; Ricker (1987) estimated the total run to be 100 million fish and Gilhousen estimated the run at 40 million fish. Prior to the development of commercial fisheries this number would have approximated the actual number of fish which entered the river to spawn or to be consumed by watershed residents such as bears, eagles, and humans. Between 1938 and 1993 the largest sockeye salmon spawning escapement was estimated at about 6.4 million (Roos 1991; Pacific Salmon Commission 1996). The percentage of current versus historic levels of escapement vary from a low of 6% to a high of 16%, which are similar to those estimated for Willapa Bay.

Are the proposed escapement goals reasonable and comparable to levels of escapement seen in other areas? As mentioned earlier, pink salmon and chum salmon escapements in the Skagit River watershed currently approach or exceed the proposed goals. Bilby (Weyerhaeuser biologist, pers. comm.), based on stable isotope analysis, believes that coho salmon escapement in small tributaries needs to be between 150 and 225 spawners/km. For the Skagit River watershed tributaries alone this would result in an escapement goal of between 46,000 and 69,000 coho salmon. While the proposed escapement goal for Skagit River chinook is substantially higher than has been managed for in the past, it does not represent a spawner escapement that is unheard of in other areas. The escapement goal is proposed to be 135 spawners/km of stream. The Pacific Fishery Management Council (1979) reported 213 chinook salmon per km as the 1970s' escapement level for the Sacramento River system with a goal of 286 spawners/km.

Can the present habitat in the Skagit River watershed support the proposed increases in spawning? The answer must be yes and no. The spawning and incubation environment currently supports chum salmon and pink salmon spawning at or above the proposed levels. However, one outcome of industrial logging and associated road building in a western Cascade mountain watershed in Oregon has been that peak flows have increased between 50 and 100% (Jones and Grant 1996). In addition to logging, the Skagit River watershed has roads, towns, housing developments, and other impervious surfaces which exacerbate runoff peaks. Recent data and observations suggest that streamflows during incubation are excessively high, leading to higher losses of eggs (D. Seiler, WDFW biologist, pers. comm.) than would occur under more moderate flows.

There is also evidence that streams may not be able to retain all of the carcasses due to manmade changes in the watershed. 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 carcasses and cycle nutrients (Cederholm and Peterson 1985, Sedell et al. 1988, Dobson et al. 1992). Much of the land abutting reaches of the Skagit River watershed accessible to anadromous salmonids is managed for industrial logging which changes the riparian area, flow regimes, and amounts of large woody debris in streams. Growns and Davis (1991) showed that 8 years after logging, there were still significant differences in the aquatic invertebrate communities between clear-cut and unlogged areas. Changes in insect communities will probably be reflected in the way nutrients from the carcasses are captured and cycled within the stream. The lowland areas of the Skagit River watershed have been leveed, diked, and otherwise constrained so that the river channel serves more to conduct water through the area than to produce fish and other aquatic and riparian resources. The river also has a series of hydroelectric dams which have blocked some areas previously available for anadromous fish spawning and have changed the flow regimes due to water storage and electrical power generation. If the Skagit watershed's present ability to capture, retain, and cycle nutrients was less than in pre-development times it will either be necessary to further increase escapements in order to actually incorporate the nutrients into the system or make improvements to the habitat.

In theory, the escapement goals for the less economically valuable, but more abundant, chum salmon and pink salmon could be raised to meet the carcass biomass goals so that present fishing patterns on chinook salmon and coho salmon would not be disrupted. This would meet the calculated nutrient needs of wintering eagles, nesting birds, and salmonid smolt production, but, it does not consider the importance of spatial and temporal distribution of different salmonid species. As noted before, the difference in smolt production related to the presence or absence of pink salmon spawners means that the spatial and temporal overlap is as critical as the number of biomass of carcasses. The only way to increase coho salmon smolt production in non-pink salmon spawning years is to increase the chinook spawning population which spawns at about the same time and often in the same areas, as the pink salmon. The timing of available carcasses was also critical to eagles. Hunt et al. (1992) demonstrated that Skagit River eagles fed first on chum salmon then on coho salmon carcasses when the chum salmon run was finished. They showed that the current fishery management plans do not provide enough coho salmon carcasses to meet the nutritional needs of eagles. Consequently, the eagles eventually left the area in search of other foods (Hunt et al. 1992).

The spatial distribution of carcasses through the watershed also needs consideration. Of the four salmon species under consideration, the chinook, pink, and chum salmons typically spawn in mainstems or in the lower reaches of tributaries. Coho salmon penetrate as far into a watershed as flows allow. In addition to the coho salmon carcasses delivering nutrients into headwater areas, there is some evidence (B. Bilby, Weyerhaeuser Biologist, pers. comm.) that steelhead trout juveniles follow the salmon upstream so that they can feed on the eggs and carcasses. This redistribution of juvenile steelhead trout puts them into an environment that was, from a historic and evolutionary perspective, more stable during winter. Consequently, increasing the number of coho salmon spawners should directly benefit the survival of steelhead trout. Dolly Varden and bull trout are regularly observed to be stationed downstream of spawning salmon, presumably to feed on eggs and insects disturbed by the spawners.

Once these goals are set can they be achieved? For pink salmon and chum salmon the answer is yes. Recent escapements for pink salmon have exceeded the proposed 500,000 spawners; continuation of current fishery patterns can achieve this escapement goal. For chum salmon, the run of fish entering Puget Sound is regularly greater than the proposed goal (WDFW files). Thus, fishery reductions could achieve the proposed escapement goal.

The situation for coho salmon and chinook salmon is more complex. In the 25 years examined, both species had total returns (catch plus escapement) to Skagit Bay that were almost always less than half of the proposed goals. These two species differ from the pink salmon and chum salmon in that an estimated 50-80% or more of the harvest occurs in fisheries outside of Puget Sound are, therefore, not controlled by Washington or tribal co-managers (Washington Dept. of Fisheries 1984). Increasing the escapement of these two species to the proposed levels will require many years in which fishing in Alaska, British Columbia, and coastal Washington will need to be constrained. Politically, this is unlikely unless there is a coast-wide recognition of the need to make similar increases in escapement throughout the species' ranges.

Salmon management, as with most other natural resource management, is imprecise. No estimate, such as run size, spawning escapement, or catch, is exact. In Washington, managers assume that errors are random and balance out over time. From this perspective, if the average spawning escapement for a species is met, then management intent has been achieved. If managers intend to annually achieve or exceed a precise escapement goal, annual fishery priorities will need revisiting.

The benefits of increased carcass deposition will accrue over time. The increased availability of carcasses will quickly translate into more and larger juvenile fish (Bilby, Weyerhaeuser biologist, pers. comm.), which should help improve their marine survival (Holtby et al. 1990). Increases in bird populations may take longer; studies where a segment of forest was fertilized showed increases in populations three years after the project began (Folkard and Smith 1995). Hunt et al. (1992) showed that the number of bald eagles wintering on the Skagit River was directly related to the magnitude of chum salmon escapement and carcass availability. Increased numbers of carcasses should increase the wintering populations. The impact of increased winter food supply on the reproductive success of eagles will need to be determined through further studies.

The increased number of spawners should also change the hydrology of the system. Montgomery et al. (1996) showed that mass spawning by salmon actually changes stream bottom composition and configuration so that a higher flow is needed to begin to scour the bed than in a stream with fewer spawners. Increased resistance to scouring should improve survival for eggs incubating in the streambed. In addition, the act of digging a redd for spawning resuspends fine sediments which are transported downstream and out of the spawning grounds.

There is a limit to the number of spawners a stream can accommodate. Since Euro-American settlement of the Skagit River watershed, a number of changes have permanently reduced the spawning area available to adult salmonids (Sedell et al. 1988, Palmisano et al. 1993, McIntosh et al. 1994, Wissmar et al. 1994). These modifications include dredging, log jam removal, dam construction, water removal for municipal and industrial use, draining and filling sloughs, and so on. The proposed goals may provide for more adults than will be able to successfully spawn in the river. However, a single large escapement which does not produce at least an equivalent number of returning adults does not necessarily indicate that excessive spawning occurred. Outside forces and catastrophic events such as floods, droughts, or ocean conditions also affect spawning in a given year. A good model for rebuilding salmon populations is the one used for Fraser River sockeye salmon. There, escapement goals were considered experimental and increased incrementally as data on total run, adult returns, spawner distribution, and spawner success, became available (Roos 1991).

The proposed escapement goals are based on the current understanding of the system and will change as spawner levels rise. For example, the chinook salmon smolt numbers are based on the smolt production by the current goal of 17,900 spawners. An escapement of 121,600 should produce substantially more smolts; their food requirements are not included in developing the goal of 121, 600. The coho salmon goal uses the number of smolts currently being trapped in the watershed. Johnson (1986) estimated that the watershed could produce about twice as many smolts. As with chinook salmon, increases in the number of coho salmon smolts were not included in the development of these goals. Hunt et al. (1992) showed that eagles follow food resources; thus more salmon on the Skagit River will attract more eagles. When the number of eagles wintering on the Skagit River exceeds the number from the winter of 1978-79, their nutritional needs will need to be factored in. Lastly, there are several different methods for estimating the energy and nutritional requirements for each group of consumers. Sibatani (1996) was using an estimate that presumed that mass was conserved; it would take 1 kg of carcass flesh to produce 1 kg of insect flesh. Piper et al. (1986) included energy transfer and waste products in their calculations of the amount of insect flesh needed to produce 1 kg of fish flesh. Hunt et al. (1992) and Stalmaster and Gessaman (1984) estimated bald eagle food needs based on observations of eagles consuming salmon during the winter. Sibatani's (1996) estimate is probably the most conservative because it assumes perfect transfer of nutrient mass. The other two estimates are probably closer to the actual nutrition need because they are based on observations of actual consumption.

The proposed escapement goals are point estimates and it is recommended that they be treated as fixed points rather than developing a range of escapements from which managers can choose. Conceptually, a range of goals offers the manager flexibility to balance available fish with the desire to harvest. Further, a range recognizes that the actual ecosystem need will, in fact, vary over time as conditions change since nature is not stable. The reality is that salmon management is imprecise and the use of a fixed point goal still results in a range of escapements (see Table 2). Anyone familiar with salmon management on the Pacific coast of North America knows that fisheries are driven by harvest. Annually, some runs are deliberately overfished in order to allow for the harvest of commingled abundant stocks. If a range of escapement goals were adopted the result would be to consistently fish to the lower end of the range. The result will be to perpetuate the current nutrient deficit.

There is at least one more question which needs to be debated. If the Pacific Northwest ecosystems evolved to process returning anadromous fish, then how many fish can be removed from the system without reducing the ecosystem's productive capacity? Before the development of canneries and product distribution systems, the carcasses generally stayed in the watershed even if they were consumed by terrestrial animals and humans. If this is how a watershed ecosystem evolved, and if the same level of terrestrial and aquatic consumers can still exist in the system, then harvests which remove the carcasses from the watershed may need to be kept much lower than today's levels of overall exploitation. There needs to be serious consideration, study, and public debate of the idea that naturally spawned populations of anadromous salmonids belong in the river. Consumptive harvests, particularly outside of the river of origin, may need to come from captive raised fish or through the selective harvest of ocean ranched fish.

Summary

A new method to develop spawner escapement goals for Pacific salmon was developed using the Skagit River watershed as an example. These goals were based on the premise that Pacific Northwest watersheds derived most of their nutrients from the annual spawning migrations and death of the salmon. Based on estimates of carcass biomass necessary to support breeding riparian zone bird populations, wintering bald eagles, and the production of stream-rearing salmonid smolts, the methodology results in recommendations that 20,400 spring chinook salmon, 101,200 summer/fall chinook salmon, 74,400 coho salmon, 500,000 pink salmon, and 178,500 and 59,000 even and odd year chum salmon be allowed to spawn. These goals should be relatively easy to achieve for the pink and chum salmons but will be more difficult to achieve for chinook and coho salmons because of the multi-jurisdictional nature of the consumptive fisheries applied to them. Further, it will be critical to ensure, through habitat restoration and protection programs, that the watershed is capable of retaining and cycling the nutrients delivered by the carcasses. The results of this study suggest that Pacific Rim watersheds need substantially more salmonid spawners than current management regimes allow. How the current level of consumption of these fish is maintained will need serious debate.

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