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Estimating Coho Salmon Rearing Habitat and Smolt Production Losses in a Large River Basin, and Implications for Habitat Restoration

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Abstract.—To develop a habitat restoration strategy for the 8,270-km^2 Skagit River basin, we estimated changes in smolt production of coho salmon *Oncorhynchus kisutch* since European settlement began in the basin, based on changes in summer and winter rearing habitat areas. We assessed changes in coho salmon smolt production by habitat type and by cause of habitat alteration. We estimated that the coho salmon smolt production capacity of summer habitats in the Skagit River basin has been reduced from 1.28 million smolts to 0.98 million smolts (−24%) and that the production capacity of winter habitats has been reduced from 1.77 million to 1.17 million smolts (−34%). The largest proportion of summer non-main-stem habitat losses has occurred in side-channel sloughs (41%), followed by losses in small tributaries (31%) and distributary sloughs (29%). The largest loss of winter habitats has occurred in side-channel sloughs (52%), followed by losses in distributary sloughs (37%) and small tributaries (11%). By type of impact, hydromodification (diking, ditching, dredging) associated with agricultural and urban lands accounts for 73% of summer habitat losses and 91% of winter habitat losses. Blocking culverts on small tributaries account for 13% of the decrease in summer habitat and 6% of the decrease in winter habitat. Forestry activities account for 9% of summer habitat losses and 3% of winter habitat losses. Limitations of the analysis and implications for developing a habitat restoration strategy are discussed.

During the period from 1880 to 1960, the rapid influx of settlers into the northern Puget Sound region of Washington and the corresponding dramatic increases in natural resource exploitation resulted in large losses of anadromous fish due to habitat degradation and overfishing. Habitat changes in the region's rivers and streams occurred on a grander scale than typically occur today, due to the construction of many federally and locally authorized projects such as hydroelectric, flood control, and irrigation dams and to diking and dredging projects. Such large-scale losses of physical habitat areas have been dramatically reduced since passage of the National Environmental Policy Act in 1970. However, losses of productive fish habitat continue as a result of incremental impacts from many small activities such as timber harvest, flood protection, and residential and urban development.

The general strategy employed by natural resource managers has been to review and address each land use activity independently, without a methodology for considering the impacts in the context of a whole watershed. In addition, administrative budgets are often developed to address new impacts, not to recoup past losses. Because complete protection is rarely achieved when permits are issued for activities such as streambank stabilization, timber harvests, and shoreline developments, the general trend will be a continued decline in the quantity and quality of fish habitat.

Prior to settlement by Europeans, the Skagit River and its tributaries were very different from their modern states. Early descriptions indicate that the lower river was generally not navigable; several large log jams blocked the river for some 2 km near the present site of Mount Vernon (Lane and Lane 1977; Sedell and Luchessa 1982). The river was free to meander across its floodplain, creating new side channels, oxbows, and distributary channels. In the lower part of the river valley, over 25% of the floodplain and delta area consisted of beaver ponds, sloughs, and wetlands (Sedell et al. 1988). In the early 1860s, the first of these floodplain areas in the lower Skagit River was claimed for agriculture by diking the river and draining marshes (Lane and Lane 1977). In the upland areas, low-gradient tributaries provided high-quality spawning and rearing habitats for coho salmon *Oncorhynchus kisutch* (Smith and Anderson 1921; Benda et al. 1992); these areas were the first to be logged in the early part of this century. Reports as early as 1921 noted many areas of habitat degradation and loss due to logging and hydroelectric dams (Smith and Anderson 1921; Lane and Lane 1977). Such conflicts between freshwater coho salmon production and increases in human settlement and other land uses are recognized throughout western Oregon, Washington, and British Columbia (Meehan 1991).

Recognizing that salmonid habitats in the Skagit River basin have undergone many changes during the past century, we began to address the problem of restoring lost or degraded habitats throughout the watershed. Because the development of such a plan requires realistic and clearly established goals (Cairns 1990), we began to ask questions about the nature of salmon habitats and their productivity prior to European settlement. This historical perspective is deemed crucial to the identification of attainable and feasible goals in habitat restoration (e.g., Sedell and Luchessa 1982; Allen and Hoekstra 1987; Newbury and Gaboury 1988). Furthermore, the development of a realistic restoration plan requires an understanding of desired conditions, the root causes of degraded conditions, the time required for the resource to recover, and the degree to which restoration efforts can effectively speed recovery (Cairns 1990; Poff and Ward 1990; Reeves et al. 1991; Allen and Hoekstra 1987).

In this study, we assessed the loss and degradation of summer and winter rearing habitats for coho salmon throughout the Skagit River basin. We focused specifically on losses of physical rearing habitats and did not address other components of habitat loss such as degradation of spawning habitats, temperature changes, or changes in water quality. Our objectives were to estimate the magnitude of lost habitat areas and coho salmon smolt production from each habitat type and to relate the magnitudes of lost habitat areas to broadly categorized land ownerships and types of impacts. In addition to the two primary goals, we attempted to quantify the amounts of summer and winter rearing habitat that are currently available in the Skagit River basin and to identify critical elements and assumptions of a limiting factors analysis for coho salmon in this river basin. As a result of these analyses, it will be possible to prioritize management efforts so as to obtain the largest gains in fish production for a given cost. Individual projects can be viewed in light of the magnitude of past losses of critical habitat, and restoration efforts can be directed towards areas that show the greatest likelihood of future coho salmon use.

Study Area

The Skagit River basin has an area of 8,270 km^2; the river drains the North Cascade Mountains of Washington and British Columbia (Figure 1). Elevations in the basin range from sea level to about 3,275 m on Mt Baker, with numerous peaks in the basin exceeding 2,500 m in elevation. Average annual rainfall ranges from about 90 cm at Mt. Vernon on the lower flood plain to over 460 cm at higher elevations in the vicinity of Glacier Peak. Several vegetation zones occur in the study area. As defined by Franklin and Dyrness (1973), most of the lower elevations are in the western hemlock zone and the Puget Sound area. These forest zones typically include western hemlock *Tsuga heterophylla*, Douglas fir *Pseudotsuga menziesii*, western red cedar *Thuja plicata*, and sitka spruce *Picea sitchensis*. Deciduous species in this area include red alder *Alnus rubra*, black cottonwood *Populus trichocarpa*, and bigleaf maple *Acer macrophyllum*. Middle elevations are in the zone of Pacific silver fir *Abies amabilis*, and higher elevations are in the zone of alpine fir *A. lasiocarpa* (Franklin and Dyrness 1973).

About 1,590 km^2 (19%) of the basin are owned privately or by the State of Washington (Table 1; Figure 2A). Land uses in this sector are predominantly agricultural and urban in the lower floodplain and delta areas, and upland areas generally support commercial forests. About 3,680 km^2 (44%) of the basin lie within the federally owned North Cascades National Park, Mt. Baker and Ross Lake national recreation areas, and Glacier Peak wilderness area; the U.S. Forest Service controls an additional 1,960 km^2 (24%) of the basin in the Mt Baker–Snoqualmie National Forest. Approximately 1,040 km^2 (13%) of the basin is in British Columbia.

Access by anadromous fishes is generally confined to streams at elevations below 700 m. Upstream migration to the Baker River system has been eliminated by the installation of two hydroelectric dams, but anadromous fish production—primarily of coho salmon and sockeye salmon *Oncorhynchus nerka*—is maintained in that system by means of trapping and hauling spawners upstream past the dams, maintaining sockeye salmon spawning beaches, and trapping and moving smolts downstream past the dams. The extent of upstream coho salmon migration in the Skagit River basin is shown in Figure 2B.

Adult coho salmon enter the Skagit River basin in late summer and early fall. Spawning is concentrated in smaller tributaries, primarily between November and January. Fry emerge from the gravel in March and April and soon establish their summer rearing territories, typically remaining in their natal streams (Sandercock 1991). Some juveniles

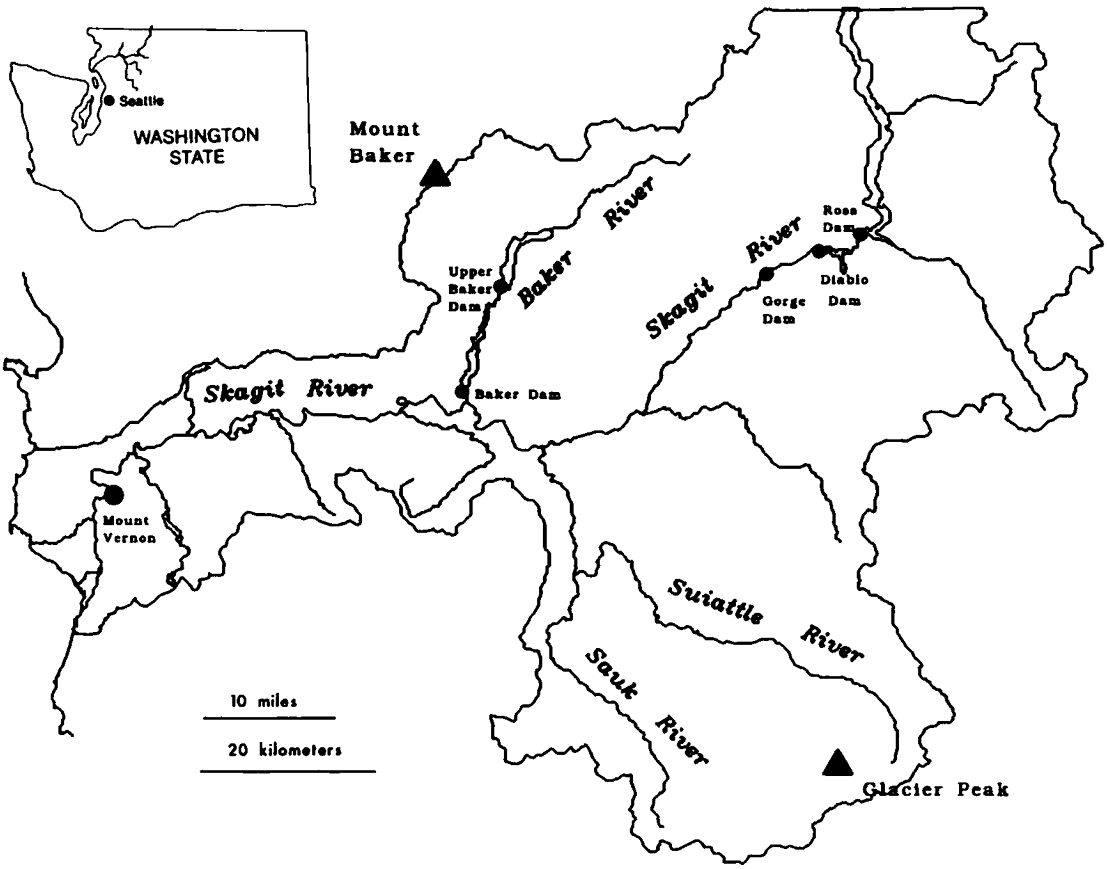

FIGURE 1.—Location of the Skagit River basin and map of major rivers.

may be gradually displaced downstream as the summer progresses (Chapman 1962). With the first fall freshets (usually in late September or October) juveniles migrate as much as 38 km downstream to winter rearing areas (Scarlett and Cederholm 1984). Preferred winter habitats include beaver ponds, off-channel ponds, and protected side channels (Scarlett and Cederholm 1984; Peterson and Reid 1984). Coho salmon smolts leave their winter rearing areas in March and April and migrate to salt water soon after.

Methods

Identification of Habitat Types

Surface waters in the assessment area were identified as one of six habitat types based on field surveys, 1:24,000-scale U.S. Geological Survey (USGS) topographic maps, 1:12,000-scale orthophotos, and National Wetlands Inventory maps (published in 1989). The six habitat types identified in this study are (1) side-channel sloughs, (2) distributary sloughs, (3) small tributaries, (4) large tributaries and Skagit River main stem, (5) lakes (including reservoirs), and (6) ponds.

Side channels are small channels branching off the main stem. They are typically abandoned river channels or overflow channels on the flood plain or on low terraces near the main stem. Distributary channels are channels that branch off the main stem on the Skagit delta and flow into the estuary as separate channels. Side channels or distributary channels with more than 90% of their areas consisting of pools were classified as sloughs. These

TABLE 1.—Areas and percentages of the Skagit River basin in various ownerships.

Ownership	Land area (km^2)	Percentage of basin
State and private	1,590	19
National forest	1,960	24
Park and recreation area	3,680	44
British Columbia	1,040	13

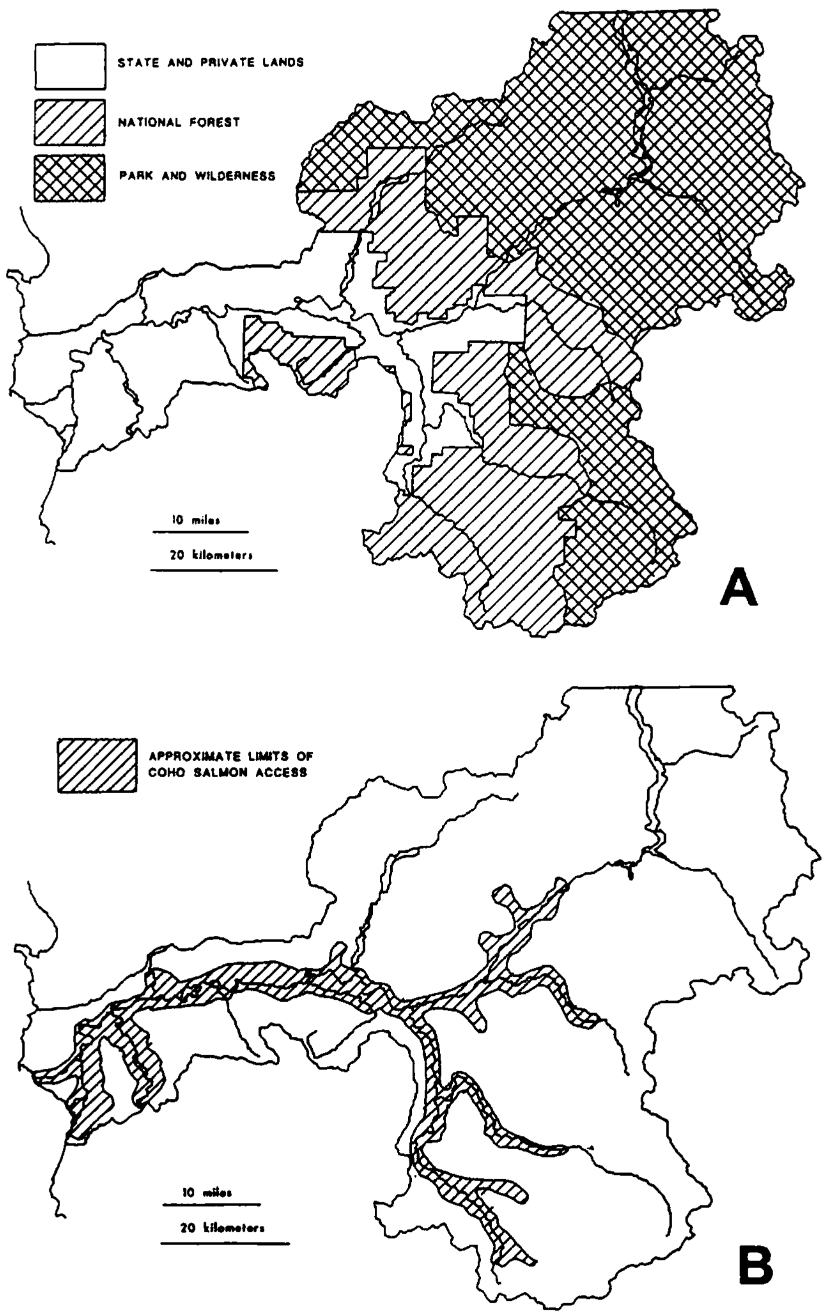

FIGURE 2.—(A) Major ownership groups in the Skagit River basin and (B) extent of coho salmon upstream migration. Coho salmon also are trapped and hauled to parts of the Baker River drainage.

areas typically maintain pool or pond-like characteristics during flooding, though relatively high velocities may occur during large floods.

Small tributaries in the Skagit basin were defined by Johnson (1986) as streams with average summer wetted widths less than 6 m. Johnson also surveyed some tributaries with average summer wetted widths between 6 and 10 m. In our assessment, we followed Johnson's classification of small tributaries and grouped these small streams into low-gradient (<2%), moderate-gradient (2–4%), and high-gradient (>4%) classes. Small tributary reaches were classed as hydromodified (diked, ditched, or dredged) or nonhydromodified. Habitat losses in tributaries that were isolated above blocking culverts or inundated by dam construction were assessed separately.

Channels with summer wetted widths greater than 6 m were classified as large tributaries or main stems (Johnson 1986) except that areas meeting the above criteria for sloughs were reclassified as side-channel or distributary sloughs. Lakes and ponds were arbitrarily distinguished according to size; ponds had surface areas less than 5 ha and lakes had surface areas of 5 ha or more.

Types of impact were identified for each area and grouped into four categories: hydropower, blocking culverts, hydromodified, and nonhydromodified. Hydromodified reaches are those that have been affected by diking, ditching, dredging, or bank protection. These areas are generally associated with lands zoned for agricultural or urban uses. Nonhydromodified reaches are generally associated with lands zoned for forestry. Impacts of forestry activities typically include loss of large organic debris and bed aggradation due to increased sediment loads. All hydropower impacts considered in this analysis are those associated with the construction of the dams in the Baker River system; they include inundation of small tributary and main-stem reaches and increases in lake surface areas, and they are associated with high mortality during smolt migration. Blocking culverts were identified throughout the basin in association with a variety of ownerships.

Side-Channel Sloughs and Distributary Sloughs

The areas of side-channel and distributary sloughs determined to be lost due to flood protection were those effectively isolated from the main river by diking, channel rerouting, and other measures. Lengths of side-channel and distributary sloughs were measured from 1:12,000-scale orthophotographs, and slough widths were measured or visually estimated in the field. The surface area of each was calculated by multiplying the measured length by the width.

We assumed that the useable area factor, rearing density, and survival to smoltification in this habitat type were similar to those of the large beaver pond habitats described by Reeves et al. (1989). Useable area factors for this habitat type were 0.75 units of habitat per square meter in summer and 0.5 units/m^2 in winter (Reeves et al. 1989) (Table 2). The number of coho salmon smolts produced from these areas during summer was extrapolated from an average rearing density of 1.7 parr per unit of habitat and a density-independent survival to smoltification of 0.25 (Reeves et al. 1989). In winter, smolt production was estimated with a rearing density of 5.0 parr/unit and a survival to smoltification of 0.31 (Reeves et al. 1989). The resulting smolt production estimates for this habitat type for summer and winter are 0.32 and 0.78 smolts/m^2, respectively. These estimates are for streams with average winter temperatures less than 7°C (Reeves et al. 1989). We also compared the smolt production estimates to local smolt trapping information to verify that the assumptions were reasonable.

TABLE 2.—*Habitat unit equivalents, parr densities in habitat units, density-independent survival to smoltification, and resultant smolt production estimates for each of six habitat types in the Skagit basin.*

Habitat type	Useable area equivalent (units/m^2)	Parr density (parr/unit)	Survival to smolt stage	Potential smolt production (smolts per area or distance)
Side channel and distributary slough				
Summer	0.75	1.7	0.25	0.319/m^2
Winter	0.50	5.0	0.31	0.775/m^2
Tributary				
Pool (summer)	1.00	1.7	0.25	0.425/m^2
Pool (winter)	0.70	5.0	0.31	1.085/m^2
Riffle (summer)	0.40	1.7	0.25	0.170/m^2
Riffle (winter)	0.00			0.000/m^2
Main stem				600/km
Pond				
Summer	1.00	1.5	0.25	0.375/m^2
Winter	0.75	5.0	0.31	1.163/m^2
Lake				25/ha

Small Tributaries

Losses in pool surface area were estimated by comparing the present-day pool area with an estimate of the historical area of pools. The pool area at present was calculated as the proportion of area as pools at summer low flow multiplied by the average summer wetted width and reach length (Johnson 1986). The historical condition was estimated by two methods: (1) a projection of pool percentage developed from the relationship between woody debris volume and pool percentage in streams of the North Cascade Mountains (T. Beechie and T. Sibley, unpublished data), and (2) the average percentage of pools in streams in unmanaged forests of the North Cascade and Olympic mountains (S. Ralph, University of Washington, personal communication) (Table 3). Because

TABLE 3.—Estimates of percentage of pools in Skagit basin streams of different gradients. Estimate 1 is from projections based on the relationship between woody debris and percentage pool (T. Beechie and T. Sibley, unpublished); estimate 2 is from the average value of percentage pools in streams of old-growth forests (S. Ralph, personal communication).

Channel gradient	Estimate 1	Estimate 2	Average
0–2%	65%	63%	64%
2–4%	45%	63%	54%
>4%	35%	35%	35%

of uncertainties in the estimates (extrapolation to old-growth conditions in method 1 and gradients estimated from topographic maps in method 2), the two estimates of the historical area were averaged to derive the estimate of historical pool area for the analysis. For each tributary reach, the estimated pool percentage for the appropriate gradient class was multiplied by the current wetted area at summer low flow (Johnson 1986) to estimate the historical surface area of pools. The corresponding increase in riffle areas was estimated similarly, except that the current and historical percentages of riffles were used in place of pool percentages. For the purposes of this assessment, all nonpool channel units (riffles, cascades, and glides) were classified as riffles. Additionally, we assumed that reaches that are presently dry during the summer were dry historically.

The net change in coho salmon smolt production was estimated by subtracting the increased smolt production in riffles from the decreased smolt production in pools. Smolt production numbers for each of the pool and riffle areas were estimated with summer usable habitat equivalents, rearing densities, and survival rates to smoltification from Reeves et al. (1989). In summer, the rearing density for pools and riffles is 1.7 parr per unit of habitat area and the survival rate is 0.25; the summer usable habitat equivalents are 1.0 for pools and 0.4 for riffles (Table 2). The estimated numbers of smolts produced from pools and riffles in summer are 0.43 and 0.17 smolts/m^2, respectively.

Pool areas in winter were calculated with seasonal data from eight similar streams in the North Cascades. We compared backwater pool areas at winter base flow to total pool area at summer low flow. The winter backwater pool areas ranged from 0 to 28% of the total summer pool area and averaged 14% (Beechie and Sibley 1990). We estimated winter backwater pool areas for historical and present conditions by multiplying the summer pool area by 0.14.

In winter, the rearing density for pools (backwater pools only) is 5.0 coho salmon juveniles per unit of habitat area and the survival rate is 0.31; the winter usable habitat area equivalents are 0.7 for pools and 0.0 for riffles (Reeves et al. 1989) (Table 2). The estimated numbers of smolts produced from backwater pools and riffles in winter are 1.09 and 0.00 smolts/m^2, respectively. We also compared the smolt production estimates with local smolt-trapping information to verify that the assumptions for both summer rearing and winter rearing habitats were reasonable.

Losses of rearing area in tributaries that have been isolated by impassible culverts or inundated by the construction of dams were also estimated. For inundated tributaries, reach lengths and gradients were measured from three topographic maps: Mt. Baker District at 1:250,000 (USGS, published in 1915), Lake Shannon quadrangle at 1:62,500 (USGS, 1952), and a survey of the upper reservoir area at 1:12,000 (Stone and Webster Engineering Corp. 1913). Wetted widths in inundated reaches of each tributary were considered to be the same as those measured in the reach immediately above the inundated reach, and historic pool areas were calculated as described above for tributaries. Pool and riffle areas above 12 of 26 blocking culverts were surveyed to estimate potential smolt production (Washington Department of Fisheries, unpublished data). Channel lengths, gradients, and wetted widths above the remaining 14 blocking culverts (Skagit System Cooperative, unpublished data) were used to calculate the historical habitat areas lost due to improper culvert installation. Pool and riffle areas in these reaches were calculated as described above for historical conditions in tributaries.

Large Tributaries and Main Stems.

We could not fully estimate the losses in habitat or smolt production from the large-tributary and main-stem river areas because coho salmon use of large rivers is not known reliably. Furthermore, we had no information regarding seasonal differences in use of the main stem, so we could not distinguish summer and winter habitat values for use in a limiting factors analysis. Coho salmon smolt production in the main stem had previously been estimated at 2,734 smolts/km (Johnson 1986). This estimate was derived from a 5-year study on the Big Qualicum River, British Columbia (Lister and Walker 1966). For main-stem rivers of glacial origin, it was assumed that half as many smolts were produced (1,367 smolts/km: Zillges 1977). A second estimate of main-stem coho smolt production is 600 smolts/km from the Bogachiel River on the Washington coast (Washington Department of Fisheries, unpublished data). The Big Qualicum and Bogachiel rivers are both somewhat smaller than the Skagit River or its major tributaries. The mean annual discharges of rivers in the Skagit basin range are 2–60 times that of the Big Qualicum and 1–30 times that of the Bogachiel. Chapman (1981) used instream flow studies to estimate usable rearing area in the Baker River (Skagit system) and then estimated that 0.42 smolts/m^2 were produced from the usable area. When we converted this information to river distance, it was equivalent to about 250 smolts/km. This value is much lower than the previously mentioned estimates, and indicates that current estimates of coho salmon smolt production per unit length of river main stem vary by more than an order of magnitude. Based on limited winter sampling in the main-stem Skagit River (electrofishing of approximately 800 sites in 36 units), we estimated that large tributaries and main stems produce a minimum of 340 smolts/km. Hence, the estimate of 600 smolts/km was considered to be most appropriate for this river basin (Table 2).

Ponds

Ponds included beaver ponds, natural ponds, and small artificial ponds. Because we were unable to estimate the amount of lost beaver pond area, we made no attempt to account for changes in the amount of pond habitat due to land uses or other causes. Present pond surface areas were taken from Johnson (1986).

To estimate the smolt production in summer pond habitat, we applied a usable area equivalent of applied a usable area equivalent of 1.0 units/m^2, a rearing density of 1.5 parr per unit of habitat area, and a survival of 0.25 (Reeves et al. 1989). The estimated smolt production was 0.375 smolts/m^2 for summer habitat (Table 2).

Because Johnson (1986) reported only the total areas of ponds in a stream rather than the sizes of individual ponds, we averaged the useable area equivalents of small and large ponds to estimate smolt production from winter habitat. For winter habitat, we used a useable area equivalent of 0.75 units/m^2, a rearing density of 5.0 parr per unit of habitat area, and a survival of 0.31 (Reeves et al. 1989). The estimated smolt production from winter habitat was 1.163 smolts/m^2 (Table 2).

Lakes

Surface areas of natural lakes were recorded by Johnson (1986). The present-day surface areas of the reservoirs in the Baker River system were recorded by S. Fransen (Skagit System Cooperative, unpublished report). The surface area of the historical Baker Lake was estimated from a survey of the upper Baker River prior to construction of the upper Baker dam (Stone and Webster Engineering Corp. 1913).

We calculated winter smolt production per hectare of lake surface area for two lake systems in the Skagit River basin. For the Big Lake system, a smolt trap was located below the outlet of Big Lake. The highest annual coho salmon smolt production over a 5-year period was 10,200 (Skagit System Cooperative, unpublished data). The estimated smolt production from winter habitat in tributaries above the trap was 3,780 smolts; by difference, 6,420 smolts were produced in the system's two lakes. Dividing by a total lake surface area of 319 ha yields a winter smolt production of 20 smolts/ha. For the Baker system, the highest recent production has been about 92,000 smolts, and a plot of smolts versus adult escapement indicates that the maximum production is about 100,000 smolts. However, it is not clear whether smolt production is limited by spawning area or rearing area. Winter smolt production in the main stem and tributaries above the trap is 31,900 smolts, leaving an estimated 68,100 smolts for lake production. Dividing by a lake surface area of 2,273 ha yields a winter smolt production of 30 smolts/ha.

For both natural lakes and reservoirs, we averaged the two estimates above to get an initial smolt production value of 25 smolts/ha. For the two reservoirs of the Baker River system, these values were adjusted based on indices of smolt bypass efficiency. Approximately 60% of the smolts are successfully transported past the upper dam, and approximately 16% of the smolts are successfully transported past the lower dam (Skagit System Cooperative, unpublished data). Therefore we used smolt production values of 15 and 4 smolts/ha for the upper and lower reservoirs, respectively. For all other lakes, a smolt production value of 25 smolts/ha was used (Table 2).

Results

Past and Present Smolt Production

Historically, larger areas of both summer (Table 4) and winter habitats were available for rearing of juvenile coho salmon. Estimates of current pro-

TABLE 4.—Estimates of historical and present areas or lengths of summer coho salmon rearing habitats in the Skagit basin, and quantitative changes in habitat.

Habitat type	Historical habitat	Current habitat	Change in habitat	Percent change
Sloughs				
Side channel	860,100 m^2	469,800 m^2	−424,200 m^2	−45%
Distributary	431,200 m^2	156,400 m^2	−274,800 m^2	−64%
Tributaries				
Hydromodified[a]	283,500 m^2	240,100 m^2	−43,400 m^2	−15%
Nonhydromodified[a]	463,600 m^2	355,000 m^2	−108,600 m^2	−23%
Culverts[b]	124,200 m^2	0 m^2	−124,200 m^2	−100%
Dams[c]	43,400 m^2	0 m^2	−43,400 m^2	−100%
Main stem[d]	632.4 km	585.6 km	−46.8 km	−7%
Lakes	735 ha	3,687 ha	+2,955 ha	+404%
Ponds	Unknown	44,000 m^2	Unknown	Unknown

[a] Pool areas in tributaries that are currently used by coho salmon.
[b] Total wetted areas in tributaries that have been isolated above blocking culverts.
[c] Total wetted areas in tributaries that have been inundated by the Baker River reservoirs.
[d] Main-stem lengths lost for coho salmon production under Baker and Shannon reservoirs.

duction levels are 0.98 million smolts for rearing limited by summer conditions and 1.17 million smolts for rearing limited by winter conditions (Table 5). Historically, the total estimated smolt production was 1.28 million smolts under summer conditions and 1.77 million smolts under winter conditions. These figures indicate a 24% decrease in smolt production capacity of summer rearing habitats and a 34% decrease in smolt production capacity of winter rearing habitats. (Smolt production capacity is defined here as the expected number of smolts produced from the available habitat area.) However, the historical totals do not include estimated losses of main-stem areas (other than those in the Baker system) or losses of ponds. Hence, the estimates of total historical production would be somewhat higher than those indicated in Table 5 if further main-stem and pond information were available.

About 34% of the historical summer smolt production capacity but only 9% of the winter capacity occurred in tributaries. Current production estimates for tributaries are proportionally similar to historical percentages: about 34% of the summer capacity and 8% of the winter capacity.

In contrast, about 58% of the historical production capacity of winter rearing habitats and 32% of summer capacity were contained in side-channel and distributary sloughs. Current percentages of total coho smolt production in sloughs

TABLE 5.—Estimates of changes in coho salmon smolt production from Skagit River habitat types under conditions of summer or winter limits on production.

	Summer-limited production				Winter-limited production			
Habitat type	Historical smolt production	Current smolt production	Change in smolt production	Percent change	Historical smolt production	Current smolt production	Change in smolt production	Percent change
Sloughs								
Side channel	274,100	149,700	−124,400	−45%	688,100	375,800	−312,300	−45%
Distributary	137,500	49,900	−87,600	−64%	345,000	125,100	−219,900	−64%
Tributaries								
Hydromodified	132,200	121,000	−11,200	−8%	44,400	37,600	−6,800	−15%
Nonhydromodified	243,300	215,600	−27,700	−11%	72,700	55,700	−17,000	−23%
Culverts	41,200	0	−41,200	−100%	37,100	0	−37,100	−100%
Dams	13,300	0	−13,300	−100%	3,700	0	−3,700	−100%
Main stem	379,400[a]	351,400[a]	−28,000[a]	−7%[a]	379,400	351,400	−28,000	−7%
Lakes	18,300[a]	48,000[a]	+29,700[a]	+162%[a]	18,300	48,000	+29,700	+162%
Ponds	44,000[b]	44,000	Unknown	Unknown	177,500[b]	177,500	Unknown	Unknown
All	1,283,300	979,600	−303,900	−24%	1,766,200	1,171,100	−595,100	−34%

[a] These estimates are based on smolt outmigrant trapping, which may more accurately reflect winter habitat values.
[b] We could not estimate historical pond areas. Current pond areas were assumed to be minimum estimates of historical pond areas.

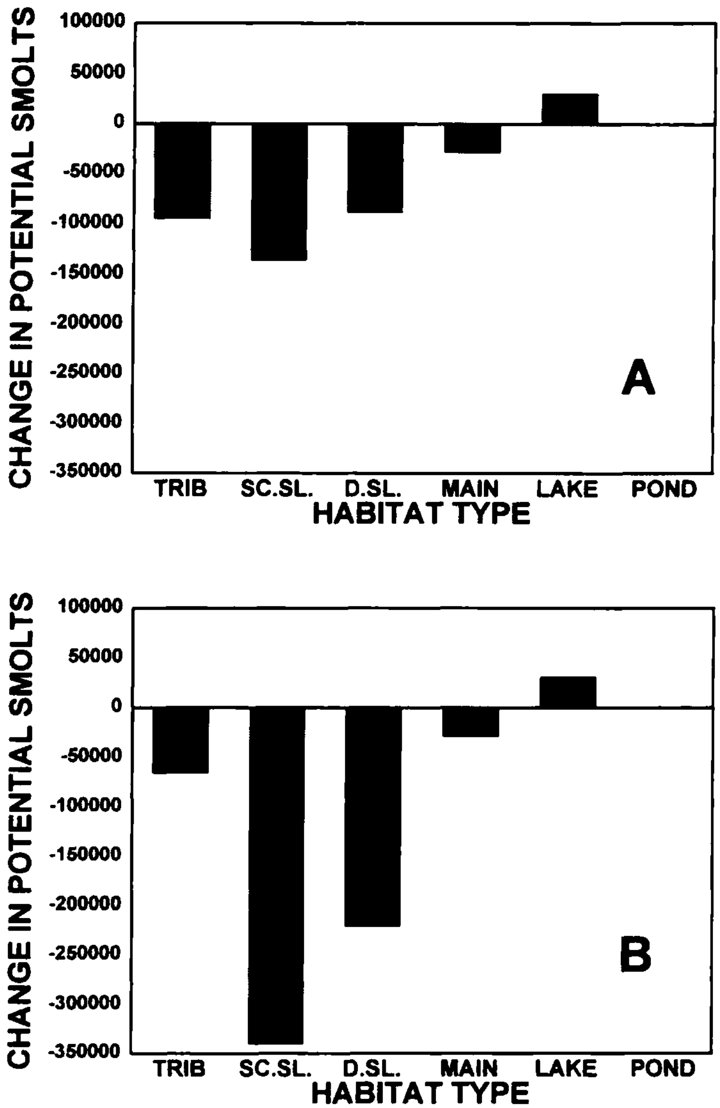

FIGURE 3.—Estimated changes in coho salmon smolt production for each Skagit basin habitat type under (A) summer rearing conditions and (B) winter rearing conditions. Habitats: TRIB = tributaries; SC.SL. = side channel sloughs; D.SL. = distributary sloughs; MAIN = main-stem rivers; LAKE = lakes and reservoirs; POND = ponds.

are lower than the historical estimates: 43% for winter rearing habitats and 20% for summer habitats.

Relative Losses by Habitat Type

The largest estimated losses in habitat area and smolt production have occurred in the side-channel and distributary sloughs (Figure 3). Over 115 km—nearly 700,000 m^2—of Skagit River side-channel and distributary sloughs have been eliminated in the past century (Table 4), and the estimated smolt production from summer and winter slough rearing habitats has decreased by 52% (Table 5).

Losses of smolt production have been about 50% greater in side-channel than in distributary sloughs (Table 5). However, the total historical area of side-channel sloughs on the floodplain was approximately twice that of distributary sloughs on the delta (Table 4). On a percentage basis, losses of the smolt production capacity have been 45% in side-channel sloughs and 64% in distributary sloughs.

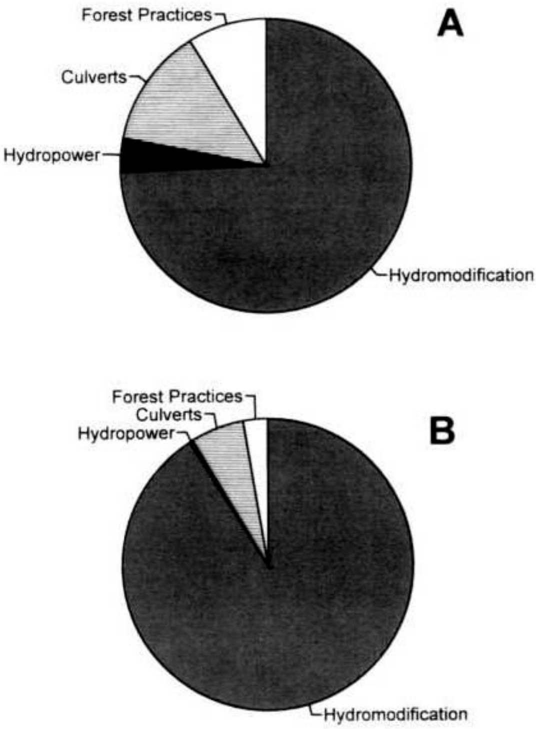

FIGURE 4.—Proportions of total losses in estimated coho salmon smolt production due to each of four types of impacts throughout the Skagit River basin for (A) summer habitats and (B) winter habitats.

The total decrease in smolt production has been somewhat less in tributaries than in sloughs. For summer habitat areas, coho smolt production in tributaries has decreased by about 93,400 fish (Figure 3A), 22%. This is approximately equal to the loss from distributary sloughs and about 44% of the loss from all sloughs combined. The loss of smolt production in winter tributary rearing areas has been only about an eighth as large as that from all sloughs combined (Figure 3B).

Habitat losses in tributaries are grouped into two categories, losses from habitats that have been degraded (hydromodified and nonhydromodified tributaries) and losses from habitats that have been completely removed from production (by culvert blockages and inundation by reservoirs). In degraded tributaries, the smolt production capacity has decreased by 10% in summer rearing habitats and by 20% in winter habitats (Table 5). In tributaries that have been completely removed from production, 54,500 coho salmon smolts have been lost from summer rearing habitats and 40,800 smolts from winter habitats.

We did not estimate main-stem changes in smolt production except for losses associated with the construction of dams on the Baker River. Main-stem loss there is about 7% of the total length of main-stem streams in the Skagit basin (Table 4). This loss estimate does not account for the main-stem habitat degradation due to channel dredging, removal of large organic debris, diking, forest practices, or other impacts.

Lake areas have increased significantly due to the construction of two dams on the Baker River. The total lake area in the watershed has increased from 732 to 3,687 ha (+404%; Table 4). The estimates of smolt production from this habitat type indicate an increase of 162% over the estimated historical production from lakes in the Skagit River basin (Table 5).

Johnson (1986) identified 12.4 km of pond shoreline in the Skagit basin. Upon reexamination of his data, we calculated the present-day pond area at 147,900 m^2 and estimated that the ponds presently can produce 44,000 coho salmon smolts as summer habitat and 177,500 smolts as winter habitat. We were not able to estimate the lost beaver pond area or the lengths and areas of streams now flowing freely through former beaver ponds.

Relative Losses by Type of Impact

Of all the major causes of lost smolt production, hydromodification has had the greatest effect on both summer and winter rearing areas in the basin as a whole. Hydromodification accounts for 73% and 91% of the total smolt production losses for summer and winter rearing areas, respectively (Figure 4). Production declines in side-channel sloughs account for approximately 57% of the total summer and winter decreases in hydromodified areas. Distributary sloughs account for 40% of the decrease in hydromodified areas and tributaries for 3%. Most of the slough habitat losses have been in the floodplain and delta areas. In virtually all cases, losses of both side-channel and distributary sloughs are due to diking of the Skagit River to protect lands zoned for agricultural, rural residential, or urban uses.

Isolation of 37 km of tributaries above 33 blocking culverts accounts for the second largest decrease of coho salmon smolt production in the basin: approximately 13% in summer rearing habitats and 6% in winter habitats (Figure 4). One of the isolated tributaries has approximately 19,000 m^2 of pond area, and the loss of winter smolt production has been especially great there.

Forestry activities account for a relatively small proportion of the total losses in smolt production: 9% in summer rearing habitats and 3% in winter habitats (Figure 4). We were unable to account for any losses due to forestry in main-stem reaches, but rearing habitats in several of the smaller main-stem reaches appear to be significantly degraded due to forestry activities (e.g., losses in pool area due to increased sediment supply, or removal of woody debris). Additionally, none of the degradation in hydromodified tributary reaches downstream of forested reaches was attributed to forestry activities. Hence, the estimated losses in smolt production due to forestry practices are believed to be low.

Within the tributary habitat type, blocking culverts are a more important source of production losses than they are for the basin as a whole. In summer tributary habitats, the 44% production loss due to blocking culverts about equals the combined losses due to hydromodification (12%) and forestry (30%) (Figure 5A). Inundation by the Baker reservoirs accounts for 14% of the total smolt loss from summer habitats in tributaries. In winter tributary habitats, 58% of the decrease in smolt production is due to impassible culverts; hydromodification, forestry, and hydropower account for 10, 26, and 6% of the winter decline respectively (Figure 5B).

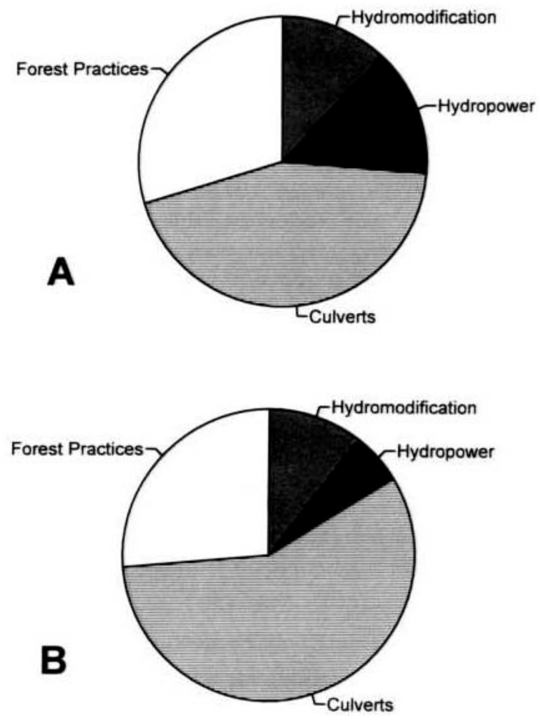

FIGURE 5.—Proportions of coho smolt production losses due to each of four types of impacts on tributary areas in the Skagit River basin for (A) summer habitats and (B) winter habitats.

Estimated versus "Measured" Production

Estimates of coho salmon smolt production made at a scoop trap at Burlington (river kilometer 25.4) from 1990 to 1992 range from 562,000 to 1,073,200 smolts and average 803,800 smolts. By the methodology presented in this paper, estimates of current coho smolt production in the portion of the river basin above Burlington are 837,800 smolts in summer habitats and 973,000 smolts in winter habitats. This compares favorably with the average and range of scoop-trap estimates in the past 3 years.

Estimates of smolt production in the entire basin were back-calculated from coded wire tag recoveries for the years 1984–1989. These estimates range from 696,600 to 1,244,100 smolts and average 914,800 smolts. Production in the entire basin estimated by the methods in this paper is 979,600 smolts in summer habitats and 1,171,100 smolts in winter habitats. These estimates also compare favorably with the average and range of back-calculated smolt estimates.

Estimates of losses in smolt production capacity in the basin are 314,400 smolts (based on summer rearing habitats) and 622,100 smolts (based on winter habitats). The decrease in summer smolt production is about 34% of the estimated smolt production from the entire basin during the past decade (914,800 smolts). If basin-wide smolt production is limited by winter rearing habitats, the loss in winter areas is 68% of current average annual production. No estimates of smolt production are available for years prior to 1984.

Discussion

Smolt Production in Tributaries and Sloughs

We compared the results of smolt-trapping studies in the Skagit River basin with the coho salmon production values generated from data in Reeves et al. (1989). From Reeves et al. (1989), we estimated that slough areas should produce 0.3 smolts/m^2 under summer-limited conditions and 0.8 smolts/m^2 under winter-limited conditions. Trapping in slough areas from 1984 through 1992 showed that coho salmon smolt production in side-channel sloughs ranged from 0.07 to 1.31 smolts/m^2 among sites and years (mean, 0.52 smolts/m^2; SD, 0.33; $N = 21$). The trap numbers provide no indication of rearing density at each life history stage or of survival from each stage, but they indicate that the smolt production numbers generated from data in Reeves et al. (1989) are reasonable for slough habitats in this basin.

In tributary areas that were not slough-like, the numbers of coho salmon trapped ranged from 0.00 to 0.71 smolts/m^2 and averaged 0.27 smolts/m^2 (SD, 0.18; N = 25). By the methods of Reeves et al. (1989), smolt production estimated for individual trap sites ranged from 0.21 to 0.41 smolts/m^2 and averaged 0.32 smolts/m^2 for summer rearing. For winter rearing, the estimates ranged from 0.02 to 0.58 smolts/m^2 and averaged 0.22 smolts/m^2. These numbers compare favorably with the 0.27 smolts/m^2 measured by smolt trapping. Again, the numbers from the smolt-trapping studies provided no indication of rearing density or survival, but they indicate that the numbers in Reeves et al. (1989) are reasonable for tributary habitats in this basin.

Assumptions of the Smolt Production Model

The smolt production model of Reeves et al. (1989) incorporates several decision criteria, including summer temperature, winter temperature, and habitat configuration (% pools). Two of the most important factors encountered in our assessment were winter water temperatures and percentage of pools in summer. When average winter water temperatures are 7°C or higher, the model estimates that rearing densities in the highest-quality summer and winter habitats are 1.7 and 1.8 parr/m^2, respectively. In contrast, when winter water temperatures are less than 7°C, the rearing densities in the highest-quality summer and winter habitats are 1.7 and 5.0 parr/m^2, respectively. This difference in winter rearing densities reflects to some degree the fewer habitat types available for rearing during winter in colder water systems; only beaver ponds and backwater pools can be used in colder systems (<7°C), whereas these plus lateral scour pools and dam pools provide useable rearing areas in warmer systems (≥7°C). The result of these differences in habitat use, coupled with differences in survival rates from summer to March (0.44 for temperatures of 7°C and higher; 0.21 for temperatures below 7°C) and beginning of winter to March (0.66 for temperatures of 7°C and higher; 0.31 for temperatures below 7°C), is that useable winter habitats in colder waters produce 4.4 times as many smolts per unit area as do summer habitats, whereas useable winter habitats in warmer waters produce only 1.6 times as many smolts per area as summer habitats. However, the amount of useable area is much higher in warmer-water systems, which offsets some of the difference in rearing densities.

In our assessment, limited temperature data throughout the basin indicated that all areas remain below 7°C for substantial periods during winter. However, data sources in the lower basin were sparse, and it was unclear whether some areas would be more appropriately assessed as systems with average winter temperatures above 7°C. The lowest elevation at which winter temperatures are recorded regularly is 85 m at the Red Creek hatchery near Sedro Woolley. Winter temperatures remain below 7°C for several weeks at this site. We found no data indicating that the average winter temperature at any location exceeded 7°C.

The percentage of pools in summer is also a key factor in determining summer rearing densities. Where less than 50% of stream area consists of pools, rearing densities are only 30–50% as high as they are in streams with pool percentages of 50% or more. The percentage pool criterion appears to be a surrogate for the overall geomorphic and habitat characteristics of a system as they relate to coho salmon production (e.g., stream gradients, available spawning area, available rearing area). For this assessment, we assumed that pool area exceeds 50% for the Skagit basin as a whole. In future analyses, it will probably be more appropriate to evaluate the entire basin as a set of interconnected subbasins. This will help to account for different configurations of habitat in different areas of the watershed.

Incomplete Main-stem and Pond Estimates

During this assessment of rearing habitat losses in the Skagit River basin, it became clear that habitats of the river main-stems may be important components of usable rearing area. The estimate of smolt production in main-stem rivers normally used by the Washington Department of Fisheries (2,734 smolts/km) appears too high for the Skagit watershed. However, we had few data to confirm our contention that the value of 600 smolts/km from the Bogachiel River was more appropriate than either the 2,734 smolts/km from the Big Qualicum river (Zillges 1977) or the 250 smolts/km estimated for the Baker River (Chapman 1981).

These three smolt production estimates for main-stem rivers suggest that the Skagit main stems may provide as little as 16% or as much as 72% of the total smolt production in the basin. If the main stems produce a large proportion of smolts (approaching 72% of the total), management strategies should emphasize protection of main-stem habitats. In contrast, if the main stem produces a low proportion of smolts, management attention should be directed to other vulnerable habitat types such as tributaries. Though we think the Skagit basin main stems produce between 36% and 41% of all the basin's coho salmon smolts (based on 600 smolts/km), the range of the estimates remains wide enough to influence management decisions and to suggest that a greater understanding of coho salmon use of river main stems is desirable.

A better understanding of main-stem rearing capacity is also important for limiting factors analysis. Estimates of current summer and winter rearing capacities in the Skagit basin are quite close, but we were unable to account for different seasonal usages of the main stem by coho salmon. A better estimate of seasonal usage of the main stem would allow a better evaluation of limiting habitat types and consequently a more focused strategy for habitat protection and restoration. During summer, juvenile coho salmon in larger rivers tend to concentrate in deep, slow water (Weigand 1991). Other studies have shown higher densities of rearing coho salmon near large organic debris cover (Dolloff 1986; McMahon and Hartman 1989; Shirvell 1990), especially during winter. However, we do not have sufficient information on usable areas or on coho salmon densities and survival in the main stems to estimate the relative values of main-stem reaches in summer and winter.

Despite indications in the literature that beaver ponds and wetlands were a large component of the habitat in the lower basin at the turn of the century (e.g., Lane and Lane 1977), we were unable to estimate the magnitude of losses of this habitat type. The missing historical component of this habitat type has little implication for a habitat protection strategy, because we have been able to provide an estimate of existing pond habitats; therefore, we can factor the current amount of pond area into the strategy.

Spawning, Seeding, and Seasonal Juvenile Movements

We did not assess spawning habitats in this study, and we do not know the extent to which survival to emergence has been affected by various land use practices. However, based on our escapement estimates (about 50,000 adults) and the estimated numbers of fry produced (2,500 eggs per redd and a survival to emergence of 0.33: Reeves et al. 1989), we estimated that 20,625,000 emergent fry can be produced in the Skagit basin. Using a survival of 0.78 from emergent fry to summer parr (Reeves et al. 1989), we calculated a summer parr population of 16,087,500. However, using the number of smolts that can be produced under summer-limiting conditions and a survival rate of 0.21 from summer parr to smolt (Reeves et al. 1989), we calculated that there is rearing space for only 4,650,000 parr. (This last estimate is partly compromised by unknown summer rearing habitat use in the main stem, and it probably underestimates the summer parr population.) Hence, it appears that summer habitats can be fully seeded even if survival to emergence and early rearing survival are somewhat low.

We assumed throughout the analysis that all habitat areas could be fully seeded regardless of their location relative to habitats for preceding life history stages. For example, we assumed that all of the 19th century summer rearing habitat in the lower-basin sloughs could be fully seeded, though it is uncertain that sufficient coho salmon spawning occurs in that portion of the basin to seed them. We also assumed that all winter rearing habitats high in the basin were accessible to summer parr, and that rearing areas for summer parr are located near all available winter areas. This becomes an important factor in deciding whether there is sufficient spawning in a subbasin to seed the available summer rearing space, and whether summer parr are able to migrate to and occupy all winter rearing areas. These questions will be addressed in the future when we evaluate juvenile coho salmon migration from summer to winter habitats within and between sub-watersheds.

Management Implications

Estimation of historical and current levels of coho salmon smolt production in various habitat types provides a basis for prioritizing habitat protection and restoration efforts in the Skagit River basin. Individual land use activities will continue to require case-by-case assessments to determine the magnitude of potential impacts. However, the evaluation of current production levels by habitat type allows us to focus protection efforts on higher-value habitat areas. Similarly, the evaluation of losses in production by habitat type allows us to prioritize restoration efforts and to target efforts where the largest gains can be made for a given cost.

Among winter rearing habitats in the Skagit basin, our analysis suggests that distributary and side-channel sloughs produce the largest numbers of coho salmon smolts, followed by main-stem areas. Current land use activities in the Skagit basin are more likely to affect side channels than main-stem habitats, primarily as a result of the cumulative impacts of many small, unrelated, and poorly regulated actions. Potential impacts on the main stem occur largely as a result of flood control activities, and existing federal and Washington State laws provide for a greater level of environmental review and protection for projects within main-stem areas. For the Skagit basin, staff resources would more efficiently be expended on developing a methodology for addressing impacts on slough habitat types rather than impacts on main-stem areas. Avenues for addressing resource protection in sloughs include cumulative-effects analysis, more in-depth habitat inventories, and greater interaction between agencies with regulatory jurisdiction. Tributaries provide relatively little winter rearing habitat in the Skagit basin, and these habitats are distributed over a much wider geographic area than are slough habitats. Hence, efforts expended to protect winter tributary habitats would likely be great, but they would have relatively small benefits for coho salmon production.

With respect to summer rearing habitats, tributaries and main stems account for more than two-thirds of the rearing area. Because the smaller tributaries are more susceptible to environmental disturbances, protection of summer rearing habitats should be directed towards these areas. We are currently unable to set priorities between summer and winter habitats because we lack knowledge concerning seasonal usage of main-stem habitats. Completion of an on-going main-stem study and refinement of the limiting factors analysis will provide information needed to better focus efforts on the habitat types that appear to be limiting coho salmon production in the Skagit basin.

Estimated reductions in coho salmon smolt production provide a clear indication of where efforts should be expended for habitat restoration. In the Skagit River system, the largest benefits can be gained by restoring side-channel and distributary slough habitats. Well over 50% of the summer and winter rearing habitat losses have occurred in sloughs. Furthermore, restoration of 1 km of isolated habitat such as a slough will result in dramatic increases in rearing area, whereas restoring 1 km of degraded tributary that has lost 10–20% of its rearing capacity will result in a relatively modest increase in production. However, additional analyses will be required to determine the likelihood that individual restoration efforts will be successful, and to identify the projects that will be most cost-effective.

This analysis also provides a basis for pursuing the restoration of other habitat types by demonstrating the cumulative effect of many small disturbances distributed across a large watershed. We can demonstrate to other land use or fisheries managers that the magnitude of losses incurred as a result of past decisions has been large and that we can target restoration measures to reclaim valuable habitat areas. For example, the restoration of fish passage at 34 culverts and other tributary blockages is a relatively inexpensive way to open up roughly 35 km of tributary habitat in the Skagit basin. Because the potential increase in smolt production is nearly equal to that of restoring over 160 km of degraded tributaries, culvert upgrading appears to be a cost-effective allocation of restoration efforts.

Lastly, this type of analysis can estimate total basin production of coho salmon if all restoration measures are implemented. Such information then can be conveyed to fisheries managers and the public at large. Publicizing the overall benefits and additional fishing opportunities that could occur might induce additional conservation support from the fishing community and from businesses dependent on recreation-based revenues.

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