Status of Anadromous Salmon and Trout in British Columbia and Yukon

By T. L. Slaney, K. D. Hyatt, T. G. Northcote, and R. J. Fielden
American Fisheries Society North Pacific International Chapter

ABSTRACT
Using fisheries agency databases and files, we assembled a summary database on the status of anadromous salmon stocks (genus *Oncorhynchus*) from British Columbia and Yukon streams. We then collected supplementary information by circulating the database among fisheries professionals and interest groups throughout British Columbia and thus identified 9,662 anadromous salmon stocks. These stocks included 866 chinook, 1,625 chum, 2,594 coho, 2,169 pink, 917 sockeye, 867 steelhead and 612 sea-run cutthroat trout stocks. We assessed the status of anadromous stocks by employing a classification scheme similar to that of Nehlsen et al. (1991). Assessments were possible for 5,487 (57%) of all stocks and included all large, commercially important stocks. The assessments found 624 stocks were at high risk, 78 were at moderate risk, 230 were of special concern, and 142 were extirpated in this century. We were unable to classify 4,172 (43%) of the stocks because of an absence of reliable data. Due to their small size, these stocks are not of great commercial importance, although they are important to the maintenance of salmonid diversity. We also identified many potential threats to anadromous salmon stocks. The absence of systematic, high-quality assessments at the biological stock level precluded reliable assignment of the specific causes for many of the stocks apparently at risk. Nevertheless, habitat degradation associated with logging, urbanization, and hydropower development contributed to most of the 142 documented stock extinctions. Furthermore, there is little doubt that overutilization by commercial and recreational fisheries has in many cases resulted in severe stock depressions that, when added to other factors, has put many stocks at risk.

Nehlsen et al. (1991) identified 214 stocks of salmon at risk of being eliminated in California, Oregon, Idaho, and Washington, highlighting both the plight of threatened stocks and the requirements for their preservation and rehabilitation. Subsequently, the North Pacific International Chapter (NPIC) and the Alaska Chapter of the American Fisheries Society (AFS) initiated similar reviews of the status of salmon stocks in their geographic areas.

The NPIC review covered all stocks originating in Canadian waters throughout British Columbia and Yukon. Its objectives were to

(1) Prepare a list of all known anadromous stocks of Pacific salmon (genus *Oncorhynchus*) in our area.
(2) Identify stocks at risk of becoming extinct.
(3) Describe the factors that have contributed to the decline of threatened stocks.

Fisheries professionals define *salmon stocks* in different ways to accommodate both scientific and management considerations (Larkin 1972; Ricker 1972; Riddell 1993). Further, stocks identified in regional databases are not consistently representative of any single definition. Given the hierarchical terminology used by Riddell (1993, Figure 1), stocks reported in regional databases represent mixtures of biological races, populations, and subpopulations or *demes*. In this paper we assessed the status of Canadian salmon stocks at two levels of organization. First, to provide a broad, familiar perspective, we examined the status of each species of anadromous salmon as an aggregate of populations on a coastwide basis. However, maintenance of maximum biological diversity requires maximizing the number of demes or subpopulations conserved throughout space and time. Consequently, our second level of analysis involved assembling and reviewing information sources on spawner abundance (i.e., escapement) in local areas, rather than catches of population aggregates, to correspond as closely as possible to the deme level of salmon stock organization. Thus, stocks identified here were most commonly synonymous with locally adapted spawning populations known to originate from spatially well-defined locations in either small streams or limited sections of large rivers or lakes. Less commonly, stocks identified here represented aggregates of locally adapted populations for

T. L. ***Slaney*** *is a biologist for Aquatic Resources Limited, 9010 Oak St., Vancouver, BC V6P 4B9; 76043.2377@compuserve.com.* ***K. D. Hyatt*** *is head of the Salmon Index Methods and Data Systems Section, Department of Fisheries and Oceans, Pacific Biological Station, Hammond Bay Rd., Nanaimo, BC V9R 5K6.* ***T. G. Northcote*** *is a professor emeritus at the University of British Columbia, 10193 Giants Head Road, Summerland, BC V0H 1Z0.* ***R. J. Fielden*** *is a biologist for Aquatic Resources Limited at the above address.*

which data were inadequate to separate them.

Methods

Information Sources

The Canadian Department of Fisheries and Oceans (DFO) and the British Columbia Ministry of Environment, Lands, and Parks (MELP) are jointly responsible for managing anadromous fish on Canada's West Coast. Personnel from these groups maintain both centralized and dispersed databases on salmon populations throughout the region. We assembled stock status information from two major databases (DFO Salmon Escapement Data System or SEDS, Serbic 1991); federal-provincial Stream Information Summary System or SISS) as well as supplementary sources, including the literature. Literature sources and local experts provided most information on stock extinctions. Wherever possible, we tried to substantiate personal communications with corroborating evidence. Information on steelhead and sea-run cutthroat trout was especially difficult to obtain and interpret because systematic observations of time trends in population size were available for few stocks. Some population trend information was available from MELP Steelhead Harvest analysis files and special assessment projects such as those on the Skeena and Keogh rivers (Ward and Wightman 1989, Tautz et al. 1992). However, the compendium of information on fish populations and habitat in the SISS database was the only provincewide source of information on these species.

Although many authors have questioned the accuracy of estimates contained within some regional databases (e.g., Pearse 1982; Tschaplinski and Hyatt 1991; Irvine and Nelson 1995), they are widely employed in regional stock assessments, and no alternatives exist for their use in the type of assessment attempted here. The advantage of the SEDS information is that it provides a geo-referenced list of salmon stocks in British Columbia. However, it contains information with many problems. Until 1984, local fisheries officers were given little guidance on how or how often their local streams were to be enumerated. In addition, resources generally limited the number of counts or visits possible. Healey (1982) summarized change in the reliability of escapement estimates throughout time, noting that fisheries officers of the 1950s had ample time to spend on escapement monitoring and were stationed in one area for long periods so they became very familiar with the local stocks. Unfortunately, they were hampered by poor access. By the 1970s, access to many spawning areas had improved, but fisheries officers had far less time to spend on escapement monitoring and were moved among areas more frequently. Personnel changes also resulted in inconsistent techniques. Since escapement estimates are very sensitive to the enumeration techniques used (Johnston et al. 1986; Tschaplinski and Hyatt 1991), the changing techniques tend to reduce the dependability of the stock information as both estimates and indices of stock size. Hence, while the SEDS system provides a convenient framework for data assembly and is the only long-term data set for most BC salmon stocks, the population data must be approached with some scepticism. The NPIC database used for stock identification was initially compiled by merging information from SISS, SEDS, published reports, and other sources. To overcome some of our concerns about the weaknesses and reliability of the NPIC database, we subjected it to verification by people with local knowledge of individual streams or populations. We summarized the data on the identity and distribution of salmon stocks by species and by areas roughly analogous to production areas for the DFO Pacific Region (Figure 2). Copies of the database were circulated among fisheries professionals and interest groups throughout British Columbia for comment and verification. We received 123 (17%) replies in response to 720 circulated copies of the database.

Slaney et al. (1996, in press) summarized the full NPIC database, which integrates stock information from all sources. This report includes stock summaries by production area as well as lists of stocks at high risk for each species.

Status Assessment

We adapted the status classifications used in this project for individual stocks from Nehlsen et al. (1991), who classified stocks as being at high risk, moderate risk, or of special concern according to an approximation of the minimum viable population for preserving genetic diversity in salmonid stocks (NMFS 1980). Classification rules rarely apply to all cases, and other approaches to assess extinction risk and persistence of stocks (Mace and Lande 1991; Thompson 1991) may be preferable, but they were impractical given the large number of stocks and limited resources involved here. The specific definitions of the categories we used were as follows:

Extinct: This category involves stocks known to have persisted in a given location for several decades but for which no returns have been observed in more than a decade.

At high risk of extinction: Nehlsen et al. (1991) described stocks in this category as declining or having escapements of less than 200 fish. However, salmonid stocks in many of British Columbia's smaller watersheds appear to persist for decades with populations of fewer than 200 fish, which may simply be limited by habitat availability. Thus, small stocks were deemed to be at high risk when the mean population in the current decade was less than 20% of the long-term mean and less than 200 fish.

Moderate risk of extinction: This category includes stocks exhibiting serious declines but not immediately threatened. These were either (1) large populations exhibiting declines to 200–1,000 fish from a long-term mean of more than 5,000 fish or

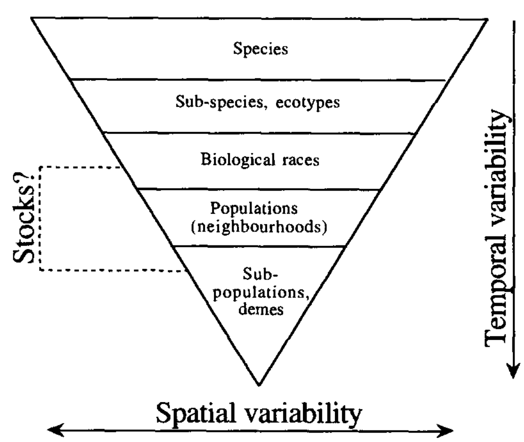

Figure 1 illustrates the hierarchy of population units, which tend to persist through time but are not always found in any one place, through to demes, which are more ephemeral but may be closely associated with one site (Riddell 1993).

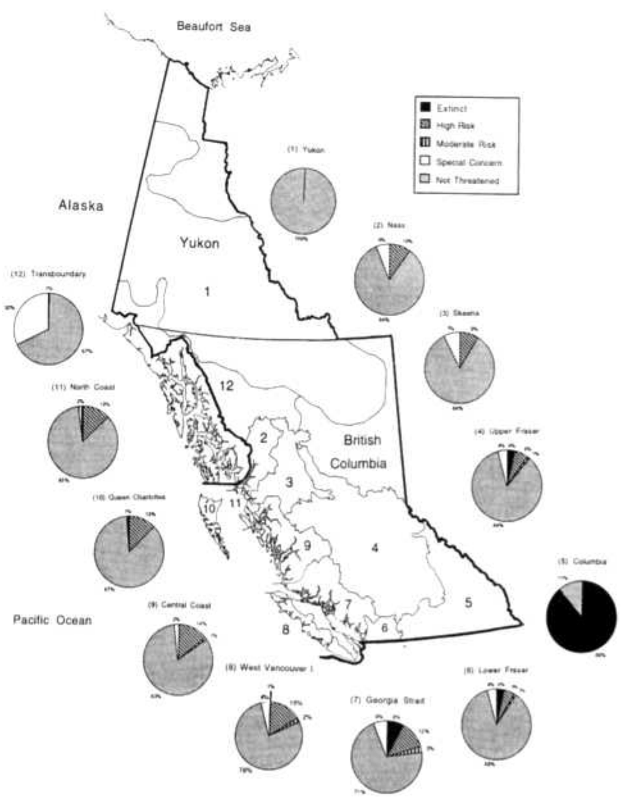

Figure 2 shows the status of anadromous salmon and trout by production area in British Columbia and Yukon.

(2) small populations reduced to less than 20% of a long-term mean of 1,000–5,000 fish.

Of special concern: This category followed Nehlsen et al. (1991) and includes stocks that (1) could be threatened by relatively minor disturbances, especially where a pending threat is known; (2) have insufficient information on population trends, but available information suggests depletion; (3) may interbreed with introduced, nonnative fish; and (4) are not currently at risk but require attention because of unique characteristics.

Unthreatened: Stocks averaging more than 1,000 fish or greater than 20% of their long-term mean abundance were regarded as unthreatened. This category includes many stocks depressed far below their maximum yield from a harvest perspective but not at risk of extinction (Thompson 1991) as defined here.

Our stock status criteria rely primarily on "face-value" analysis of escapement observations contained in the SEDS database, which may bias stocks for inclusion in various status categories depending on whether their index numbers are biased high or low relative to their true abundance (e.g., Tschaplinski and Hyatt 1991). Similarly, status classifications are influenced by the temporal bounds adopted during analysis where longtime series suggest different conclusions than short-term ones. Wherever possible, we based NPIC stock status classifications on comparisons between mean escapement during the last decade and the mean during the 40 years prior to and ending in 1992. However, because population information on small stocks, especially steelhead and sea-run cutthroat trout, was limited, it was often necessary to base classifications on the judgment of local experts.

Threats

We collected information on threats to populations at risk and classified these threats according to categories (e.g., habitat degradation, overutilization, disease) used by Nehlsen et al. (1991). However, in most cases we found more than one threat, and the causes of stock declines were confounded. Consequently, we turned to information of a more regional nature to identify the major forces controlling stock trends.

Results

Coastwide abundance trends by species

Information on long-term trends in abundance (as measured by escapements) was available for British Columbia and Yukon stocks (excluding those in the Columbia River) in five of seven species examined (chinook, coho, pink, sockeye and chum salmon, Figure 3). Four of the species exhibit trends for either stable (chum) or increasing (chinook, sockeye and pink) escapements. Sockeye and pink salmon increases appear to be attributable to the combined effects of stock rebuilding and enhancement activities focused on stocks originating from the Fraser (Henderson 1991; Northcote and Atagi 1996) and Skeena rivers (West and Mason 1987) during an interval of favorable marine production (Beamish and Bouillon 1993). Similarly, recent catch stabilization and escapement rebuilding trends for chinook salmon appear to have been principally driven by management and stock conservation actions initiated through the U.S.-Canada Salmon Treaty.

Coho abundance trends contrast sharply with other species by exhibiting a long-term decline in escapement (Figure 3) combined with a recent precipitous decline in catch throughout our region. Further, the decline of wild stocks in some areas such as Georgia Strait is likely even greater because increased catches of hatchery coho have masked the true degree of wild stock decline (Walters and Cahoon 1985; Anonymous 1992). Little general agreement can be found about the precise contribution of specific causes or, given data quality concerns, even the magnitude of this decline (Anonymous 1992). However, degradation of freshwater habitat (Tripp and Poulin 1992; Tripp 1994), overexploitation (Walters 1995; Hatfield Consultants, Ltd. 1996), and variations in the productive capacity of the marine environment (Beamish and Bouillon 1993) have all been implicated. To summarize *at the species aggregate level of organization*, salmon stocks in the British Columbia and Yukon area appear, with the exception of coho, to be either stable or increasing. The long-term picture that emerges at the species aggregate level suggests that, in spite of the many imperfections in land use and harvest management practices, salmon originating from Canadian waters—though fluctuating considerably during recent decades—have not undergone major declines (except for coho). Some species (sockeye, pink, chinook) have increased. However, assessments at the aggregate level often mask problems in the maintenance of biodiversity, which must be appraised at the individual stock level considered below.

Classification of Identifiable Stocks

We identified 9,663 anadromous salmon stocks in the British Columbia and Yukon study area, including 866 chinook, 1,625 chum, 2,594 coho, 2,169 pink, 917 sockeye, 867 steelhead, and 612 sea-run cutthroat stocks (Table 1). These estimates are unlikely to be highly accurate in an absolute sense because some stocks identified in the SEDS database are actually aggregates of several biological populations, while SISS files frequently confer "stock" status on local concentrations of fish on the basis of limited observations. On balance, the number of stocks identified here probably represents a minimum estimate of those that are present with some bias toward overrepresention of important commercial species (e.g., chinook)—which are well documented—but underrepresentation of poorly assessed species (e.g., sea-run cutthroat trout). Status classifications were possible for 5,491 stocks (Table 1), 57% of those identified. In accordance with the pattern at the coastwide aggregate level, the largest group of stocks in our region (46%) was unthreatened (Figure 4). However, 624 (11%) of the classifiable stocks were high risk; 78 (1.4%) were moderate risk; 230 (4.1%) were of special concern; and 142 (2.5%) were extinct. The adequacy of quantitative information for classifying stocks by species varied greatly. Classification was possible for more than 69% of all chum and pink stocks but impossible for 48% to 80% of identifiable steelhead and sea-run cutthroat stocks, respectively. Among the classifiable stocks, more than 80% of pink, chum, and sockeye stocks were unthreatened, while the species with the greatest proportions of stocks at high risk were coho (16%) and sea-run cutthroat trout (13%). Extinctions appeared highest for sea-run cutthroat trout (13%), moderate for chinook and sockeye (4%), and lowest for pink salmon (1%).

Extinctions

We documented 142 stock extinctions (Table 2), excluding stock losses that occurred after European contact but before the development of systematic records. Commercial fishing began in the 1830s and commercial canning in 1866 (Lyons 1969). Catch is thought to have peaked during the Fraser River 1899–1902 sockeye cycles (Ricker 1987), but spawner enumeration for major stocks did not begin until the turn of the century, and no attempt was made to organize regional spawner abundance (i.e., escapement) records until 1929

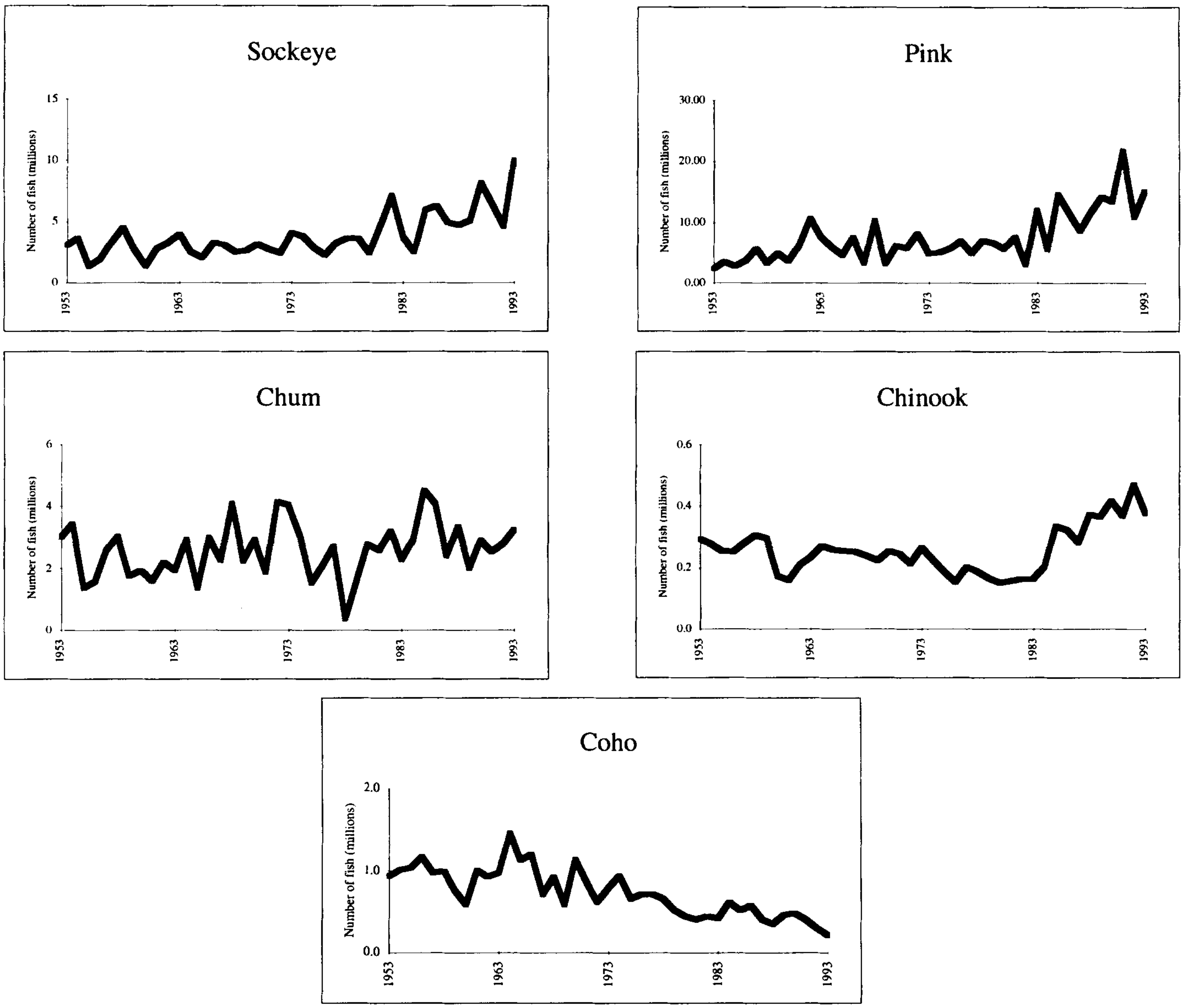

Figure 3 represents escapement trends for all salmon stocks monitored by the Department of Fisheries and Oceans in the Pacific Region of Canada from 1953 to 1993 (Source: SEDS database).

Table 1 summarizes stocks of British Columbia and Yukon salmon and trout that were classified following the system of Nehlsen et al. (1991).

Species	Extinct	High risk	Moderate risk	Special concern	Unthreatened	Unknown	Total stocks	% of stocks in region
Chinook	17	47	6	7	330	459	866	9.0
Chum	22	141	12	11	966	473	1,625	17.0
Coho	29	214	22	21	1,024	1,284	2,594	27.0
Pink	17	137	21	17	1,298	679	2,169	23.0
Sockeye	20	61	2	1	463	370	917	9.5
Steelhead	9	8	10	143	282	415	867	9.0
Cutthroat	15	16	5	30	54	492	612	6.3
Unspecified	13						13	0.1
Totals	142	624	78	230	4,417	4,172	9,663	100
% of stocks in region	1.5	6.5	0.8	2.3	46	43	100	

(McNairnay 1987). Further, salmon occur in streams scattered across 917,000 km^2 and 2,700 km of coastline in British Columbia and a further 294,000 km^2 in Yukon, much of which remains remote and difficult to access. Consequently, even today, stock status and especially extinctions are difficult to verify because the majority of small stocks are inspected too infrequently and with too little effort to establish whether the stock is extinct or contains too few fish to be readily observed. Our unknown category includes 920 stocks that have mean escapements of 0 fish in the current decade, despite being examined on more than one occasion. Some of these stocks are certainly extinct; however, without information on the effort expended searching for them and on the number of verifiable years of 0 returns, their losses cannot be confirmed, and estimates of extinctions are biased low. The problem is best illustrated by the apparent lack of extinctions in the Queen Charlotte Islands (Table 2), which results from the absence of corroborating evidence for any of the 68 systems in that area with a mean escapement of 0 in the current decade. This contrasts with the results of Shirvell and Charbonneau (1984), who identified 29 extinct stocks in these islands and noted that stocks were disappearing at a rate of nearly 4 per year. They defined extinctions as a 10-year period of "none observed" and "unknown" in the escapement record.

The effects of hydropower and urban development are illustrated by the concentration of extinction reports in the Georgia Strait and Columbia areas (Table 2). Harris (1978) and DFO (1994) documented a number of the British Columbia stocks known to have been lost through urbanization based on research on the history of the Vancouver area. However, little information is available on similar losses in other urban centers of British Columbia. For example, the topography of Victoria, an older city, suggests that many small creeks and salmon stocks may have existed there once, but information on them is not readily available.

Geographic Trends

The number of stocks identified by production area varied from 2 in the Liard River to 1,496 on the Central Coast (Table 2). Regardless, some areas had higher proportions of stocks at risk than others. The Central Coast displayed the greatest number (153) of stocks at high risk. However, southwest Vancouver Island exhibited the greatest proportion of stocks at high risk (53 stocks or 17%). Johnstone Strait and the Vancouver Island side of Georgia Strait also displayed high proportions (>14%) of stocks classified as high risk.

Chinook

Information to support chinook status classifications was available for 407 stocks (47%) (Table 1). Of these, 47 were at high risk of extinction; 6 were at moderate risk; and 7 were of special concern. In addition, 330 (38%) stocks were not threatened, and status information was unavailable for a further 459 (53%). While chinook salmon had an overall proportion of stocks at high risk similar to those of the other species (12% of those known), some production areas were much higher. In southwest Vancouver Island, 14 of 65 stocks (36%) were at high risk of extinction. We also observed rates greater than 20% for Queen Charlotte Islands, northwest Vancouver Island, and the Vancouver Island side of the Strait of Georgia. All but 15 of 47 chinook stocks thought to be at high risk of extinction were classified on the basis of SEDS information, and thus the reliability of some estimates may be doubtful. Nonetheless, they do present cause for widespread concern.

Most of the chinook stocks in this category have always been small, although Toba River chinook had a mean escapement of 2,500 fish from 1953 to 1992, dropping to a mean of 154 in the 9 counts made from 1984 to 1993. Chinook in the mainstem Thompson River declined similarly from 1,612 to 92, although only 3 counts were made in the past 10 years.

Only seven chinook stocks were reported in the Queen Charlotte area. Among these the Ain stocks have fallen to very low levels and may actually be extinct. In the southwest Vancouver Island area, 14 stocks were classified at high risk of extinction. This includes the Sarita, Franklin, Nahmint, Henderson, and Toquart stocks, which may have been overharvested in mixed stock fisheries targeted at the more numerous Robertson Creek hatchery stock. Puntledge River fall and spring chinook both have long-term mean escapements of 1,900 fish. However, in recent years the 2 runs combined have totaled 50–400 fish. The decline appears to be related to a range of problems, including high water temperatures, channelization, dams, seal predation, and acid mine drainage (H. Geno, DFO, personal communication).

Seven chinook stocks were classified as being of special concern (Table 1). The Ishkeenickh stock in the Nass area, as well as the Sooke stock on southwest Vancouver Island, appear to be severely depressed, although causes are not known. Returns of the Nechako stock in the Upper Fraser area in 1993 and 1994 have been close to one-third of the 1984–1992 decade average, and the maintenance of the stock depends on a river regulation agreement whose status is under review at this time. Further east, the Louis and Lemieux stocks in the North and South Thompson area are now less than half their former size. Logging and agriculture are thought to contribute to the problem (M. Galesloot, Shuswap Nation Fisheries Commission, personal communication).

We counted 17 extinct chinook stocks (Table 1). In the Columbia, Lower Fraser, Upper Fraser, and North and South Thompson, 11 of these occurred as a result of hydroelectric dams. The Wahleach River in the Lower Fraser was dammed in 1952; however, its chinook stock had been listed in the annual assessments as "not observed" since 1941. Causes of the other losses have not been reported.

Chum

More information is available for chum salmon stocks than for the other species. Only 473 stocks (29%) could not be classified (Table 1). However, no information is available on the Liard stock, and less than half the chum stocks in the Transboundary, Yukon, North Coast, and Nass areas could be classified. Among the 1,625 chum stocks reported were 141 stocks (12% of those classifiable) that appeared to be at high risk of extinction, 12 at moderate risk, and 11 of special concern. In addition, 966 stocks (84%) were unthreatened.

The greatest proportion of stocks at high risk occurred in the Nass with 10 stocks (31% of the area's classifiable stocks). This was followed by the North Coast with 11 stocks (24%) at high risk. Stocks at high risk were more numerous in the Queen Charlotte (22) and Central Coast areas (38), although they formed a smaller proportion of the classifiable stocks.

No chum stocks at risk were observed in the Yukon, Transboundary, and Liard areas, although the species exists in all three. Chum do not generally migrate above Hells Gate on the Fraser system, although they are recorded in two systems in the Upper Fraser area. Thus, the Upper Fraser area has two unthreatened stocks, but there are none in the Upper Fraser/ Thompson or North and South Thompson areas, which are tributary basins.

We counted 22 extinct chum stocks, 17 of which occurred in the Vancouver area and were reported by Harris (1978). Additional chum stock losses in the Georgia Strait (Vancouver Island) area include the Airport, Sandhill, Bowker, and Colquitz stocks. The Jordan River chum in southwest Vancouver Island was destroyed as a result of hydropower operations.

Most of the chum stocks at high risk of extinction have always been small. However, the Kwinimass, Georgia, Bear, Koeye, Dean, Keogh, Kliniklini, Klite, Little Toba, and Henderson stocks all had mean 1953–1992 escapements of > 1,500 fish but were less than 300 in the current decade (SEDS data). The largest change observed was in Kliniklini chum, where the 1953–1992 mean was 9,770 chum, although the current decade mean has been only 160 fish. However, the Kliniklini figures may not be reliable and illustrate some of the common problems with SEDS information. The Kliniklini River is remote, has a September mean flow of 443 $m^3 \cdot s^{-1}$, and is opaque with glacial silts such that spawners are difficult to observe except in a few clearwater tributaries. A decline does appear to have happened, but it is impossible to verify that the stock has crossed the high-risk threshold of less than 200 fish.

Eleven chum stocks are of special concern. In the Georgia Strait (mainland) and Lower Fraser areas, the Langdale, Schoolhouse, Sutter, and Brunette stocks all suffer from habitat degradation associated with urbanization. Escapements for the remainder of the chum stocks in this classification have declined by almost 50% in the last decade, although they are not yet at risk. The Orford River stock in Johnstone Strait was added to the list as a result of the 1994

Table 2 shows the status of British Columbia and Yukon salmon stocks within each of the production areas shown in Figure 2.

Production area	Extinct	High risk	Moderate risk	Special concern	Unthreat-ened	Unknown	Total stocks	% of stocks in region
Liard	0	0	0	0	0	2	2	0.02
Yukon	0	0	1	0	15	64	79	0.82
Transboundary	0	0	0	22	46	309	378	3.90
Nass	0	27	0	16	233	275	551	5.70
Queen Charlotte Is.	0	84	6	2	557	419	1,068	11.00
Skeena	2	44	1	38	432	435	952	9.80
North Coast	0	41	5	0	267	271	584	6.00
Central Coast	1	153	11	15	827	489	1,496	15.00
Rivers and Smith Inlets	0	9	0	9	133	85	236	2.40
NW Vancouver Is.	0	43	4	9	289	336	681	7.10
SW Vancouver Is.	0	53	10	20	220	317	625	6.50
Johnstone Strait	6	62	15	25	346	343	797	8.30
Georgia Strait Vancouver Is.	26	31	10	27	130	169	393	4.10
Georgia Strait Mainland	57	40	10	19	309	296	731	7.60
Lower Fraser	14	18	3	14	347	225	621	6.40
Upper Fraser/ Thompson	8	11	0	5	147	92	263	2.70
N & S Thompson	6	8	2	9	117	44	186	1.90
Columbia	17	0	0	0	2	1	20	0.20
Totals	142	624	78	230	4,417	4,172	9,663	100
% of stocks in region	1.5	6.5	0.8	2.4	46	43	100	

return, which was only 2,000 fish, although both the long-term and recent decade averages had been 29,300 fish.

Coho

Status information was available for approximately half of the coho stocks examined. Among these, 214 (16%) were at high risk of extinction; 22 were at moderate risk; and 21 were of special concern (Table 1). In addition, we noted 29 extinct coho stocks, half of them located on the mainland side of Georgia Strait. The Central Coast area had the highest number of stocks at risk in both absolute terms (54 stocks) and as a proportion of the total coho stocks in the area (26%). Large numbers (20%) of stocks at risk were also noted in the Johnstone Strait and southwest Vancouver Island areas.

Information on coho escapements is both unreliable and difficult to obtain. The DFO and volunteer groups operate counting fences at a number of locations, but most of the SEDS data are based on visual accounts. These are particularly unreliable for coho since the fish return late in the year and are very cryptic while in freshwater (Waldichuck 1984). In addition, they often enter coastal systems under freshest conditions. High water and early winter snows also hamper stream access for enumerators. As a result, less than half of the stocks in the Transboundary, Nass, Skeena, Upper Fraser/Upper Thompson, southwest Vancouver Island, Georgia Strait (Vancouver Island), and Queen Charlotte Islands areas could be classified.

Most of the coho stocks at high risk in British Columbia and Yukon have always had escapements of less than 1,000 fish. However, the Toba River in the Georgia Strait (mainland) area had a mean escapement of 8,417 coho in 35 annual escapement estimates during 1953–1992 but had dropped to 289 coho in 9 estimates during 1984–1992. Other stocks that now number less than 200 fish but formerly had escapements of more than 1,500 fish include those from the Morice, Endhill, Klite, Little Toba, Brem, and Clayoquot rivers as well as the Eagle and Kakushdish creeks.

Five of the 21 coho stocks of special concern, including the Langdale, Schoolhouse, Sutter Brook, and Brunette stocks of the Georgia Strait (mainland) area, suffered from habitat degradation associated with urbanization. On southwest Vancouver Island, the Klanawa, Blue, and Ralf stocks are all chronically underseeded. The remainder of the coho stocks in this classification are thought to suffer from interception in mixed stock fisheries. Finally, the Musqueam stock, which numbers less than 50 fish annually, is the last native salmon within the city of Vancouver.

Pink

We identified 2,169 pink salmon stocks (Table 1), and population information was available for 70% of them. We deemed 1,298 stocks (87%) unthreatened, while 137 (9%) were at high risk of extinction; 21 were at moderate risk; and 17 were of special concern. The 87% unthreatened proportion was the highest of the 7 salmonid species considered.

Seventeen pink salmon stocks were listed as extinct. However, this number is unrealistically low since no breakdown is available of the individual pink salmon stock losses that resulted from the Hells Gate slide on the Fraser River in 1913 (Ricker 1989). In the odd years prior to the slide, 37 million pink salmon spawned in streams above Hells Gate. Some of these systems have been recolonized following construction of fishways.

The largest proportion of pink salmon stocks (31%) at high risk of extinction occurred on the west coast of Vancouver Island. Large numbers of stocks at risk were also observed in the Queen Charlotte Islands, where 29 stocks (13%) were at high risk. Notable among the British Columbia pink salmon stocks at high risk of extinction is the Stranby River stock in Johnstone Strait, which declined from a 1953–1992 average of 16,500 fish to 50 fish in 1983–1992. The Kauwich stock on northwest Vancouver Island declined similarly from 11,300 to 4 fish.

Pink salmon stocks of special concern result mainly from precipitous declines in escapement, although all are still above the risk of extinction thresholds. The exceptions are the Campbell River stocks, where escapements have increased, but the native stocks may have declined as a result of introgression by fish from Quinsam Creek hatchery.

Sockeye

We found stock status information for 547 (60%) of the 918 stocks identified. Among these were 463 (50%) unthreatened stocks, 61 (7%) at high risk of extinction, 2 (0.2%) at moderate risk, and 1 (0.1%) of special concern (Table 1). The highest proportion of stocks at risk occurred in the Johnstone Strait area (30%), although high proportions of stocks at risk occurred in the North Coast, Skeena, Central Coast, Nass, and Georgia Strait (Vancouver Island) areas as well.

The 20 sockeye extinctions we found formed the highest proportion among the species examined (2.2%). Six of these were from the Columbia area and were destroyed as a result of dam construction in the United States. Dams also caused the extinction of the Coquitlam and Alouette stocks in the Lower Fraser area. An additional five stocks became extinct as a result of the Hells Gate slide on the Fraser River and overfishing in the following two decades (Ricker 1987).

Sockeye stocks at high risk of extinction include three (Bear Lake, Klinaklini, and Mackenzie Sound) that had 1953–1992 mean escapements of more than 1,000 fish. The Bear Lake stock appeared to be harvested coincidentally with larger Skeena River stocks. However, no information was available on the other declines. We included two stocks in the high-risk group despite the fact that their 1982–1992 escapements exceeded the thresholds for this classification. The Fairfax stock in the Queen Charlotte Islands has had mean escapements of 406 fish during the last decade. However, it is dependent on an abandoned dam and fishway system. This stock may become extinct if resources are not dedicated to the problem. The Nithi stock in the Upper Fraser area has had a 1953–1992 escapement average of 290 fish. It now appears to be at high risk of extinction, although the recent decade escapements have averaged 114 fish. The Nithi stock appears to suffer from problems typical of small, upriver stocks, including logging and urbanization in the watershed as well as coincidental harvest with larger stocks along the migration route. The remainder of the sockeye stocks at high risk has always been small. Incidental harvest has been suggested as contributing to the declines of at least 30 sockeye stocks in the Skeena/North Coast area. However, we could not ascertain the causes of the other declines.

The only sockeye stock classified as being of special concern was the lower Babine River sockeye in the Skeena area. Although the 1983–1992 mean escapement of 9,500 fish is still well above the risk thresholds, it is only 20% of the longer-term average.

Steelhead

We identified 963 steelhead populations, although some of these appear to represent composite stocks. Allowing for those reduced the total to 867 stocks, which were distributed through all parts of the study area except the Yukon and Liard systems. Eight (1%) of the stocks located in the Georgia Strait (mainland) areas and Lower Fraser River were at high risk of extinction. An additional 143 (16%) stocks were deemed of special concern largely as a result of interception in net fisheries targeted on other species.

High risk of extinction in the Puntledge River steelhead stocks is associated with hydropower operations, other disturbances in the watershed, and interception in the commercial fishery. On the mainland side of Georgia Strait, the MacKay, Eagle, and Nelson stocks are at high risk as a result of watershed urbanization. Other steelhead stocks at high risk include the Chehalis summer stock in the Lower Fraser and the Stein, Seton, and Bridge stocks in the Upper Fraser/Thompson area. British Columbia steelhead extinctions associated with hydrodevelopment include the Capilano (summer) stock in Georgia Strait (mainland), Stave River (summer) stock in the Lower Fraser area, and Okanagan Lake, Columbia, and Pend Oreille stocks in the Columbia area. In the Georgia Strait (mainland) area, urbanization resulted in the loss of the China Creek, Brunette, and Blenheim stocks early in the century, while the Mosquito Creek (summer) stock was last observed in the mid-1980s.

Sea-run Cutthroat

Anadromous cutthroat stocks were reported from all parts of coastal British Columbia. However, no reports came from the northern systems, the Columbia basin, or other inland areas where a major migration is required. We noted 612 stocks, but status information was available for only 120 (20%) of them (Table 1), 44% of which were unthreatened. Little status information was available for sea-run cutthroat stocks outside the Georgia Strait/Lower Fraser River area. That area includes 14 populations at high risk of extinction, 4 at moderate risk, 27 of special concern, and 15 already extinct. Sea-run cutthroat had the lowest proportion of unthreatened stocks (45%) among the species examined but by far the largest percentage (more than 80%) of stocks in the unknown status category.

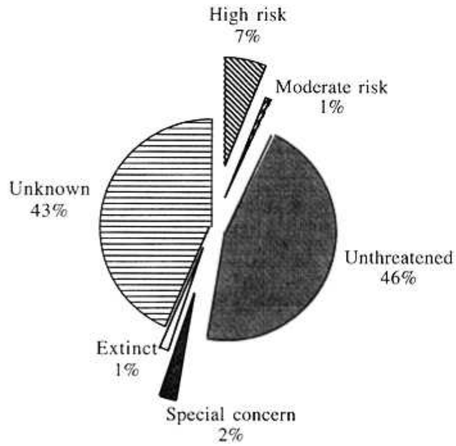

Figure 4 summarizes the status classifications of British Columbia and Yukon anadromous salmon and trout stocks.

The problems of stock identification mentioned earlier were particularly acute in anadromous cutthroat trout. First, establishing which of the coastal populations were anadromous was difficult. Many small coastal streams support cutthroat trout, but anadromy is only one of four coastal cutthroat life history patterns (Trotter 1989). A further problem in identifying sea-run cutthroat stocks is that populations in adjacent streams may form single stocks (Campton and Utter 1987). Information linking stream populations in this way was available only for the Vancouver Island portions of Johnstone Strait, the two Georgia Strait areas, and to a lesser extent the Lower Fraser area. However, it was entirely lacking for the remainder of the province. Together, these problems make the stock numbers for northern British Columbia and the west coast of Vancouver Island uncertain.

Operation of hydropower dams on the Jordan and Stave rivers has reduced habitat capability in those systems, and the sea-run cutthroat stocks are at high risk of extinction. The remainder of the sea-run cutthroat stocks at high risk are associated with streams suffering from urbanization problems such as encroachment, channelization, reduced habitat complexity, and low summer base flows. In the Georgia Strait (Vancouver Island) area, 12 sea-run cutthroat stocks were deemed of special concern. Most of these were a result of habitat degradation. Prominent among these are the French Creek and Deep Bay composite stocks, which are very small, inhabit 10 small creeks in a rapidly developing area, and require conservative husbandry. In the Georgia Strait (mainland) area, the Langdale and Dakota stocks are of special concern as a result of declining escapements and urbanization effects in their watersheds. Urbanization and agricultural effects also resulted in special concern classification for nine stocks in the Lower Fraser area.

Threats to Salmon and Trout Stocks

Currently, no comprehensive inventory of threats to salmon stocks in British Columbia or Yukon exists. This is due in part to an agency separation of stock management and habitat protection functions and because central databases such as SISS relate habitat problems to watersheds rather than particular stocks. However, the deficiency also reflects the difficulty in identifying the causes of stock declines. There are few cases where one threat is entirely responsible for a decline to critical levels. More often, stock risks reflect the interaction of many problems.

(1) Habitat destruction by human activities.

Fish habitats in British Columbia and Yukon are better preserved than those in many other parts of the world. However, the region has undergone extensive changes in land use and forest cover during the last hundred years, particularly in coastal areas (Figure 5). Fisheries values were seldom foremost in this development process. A pollution control permitting system has been in place since 1971 (Servizi 1989), and the federal Fisheries Act and associated "no-net-loss" policy (DFO 1986) provide tools for habitat protection, but they are difficult to apply.

Forestry has been a leading industry in British Columbia for most of the last century, and removal of forest cover has been the major perturbation in many watersheds. The direct impact of logging appears to be a complex series of changes that result in increased growth at some life stages and reduced survival at others (Hartman and Scrivener 1990). Logging impacts at Carnation Creek on the west coast of Vancouver Island included increases in erosion, sedimentation, and summer water temperatures (Holtby 1988). Other concerns include loss of riparian cover, reductions in large organic debris, and changes in habitat unit characteristics (Tripp and Poulin 1992). In addition, associated activities such as road construction, log storage, and herbicide spraying may have led to further fish habitat degradation. In coastal areas of the province such as the Queen Charlotte Islands, logging on steep slopes and heavy precipitation have been associated with increased frequency of slides, debris torrents, and loss of stream habitat for salmonids. Tripp and Poulin (1992) reported the total destruction of salmonid-rearing habitat in some small streams after such events. The relationship between logging and fish production in the interior of the province is less understood, although differences in climate and hydrology are thought to be significant (Slaney et al. 1977; MacDonald et al. 1992). Poorly planned logging road construction through post-glacial lake deposits in tributaries of the Upper Fraser River has resulted in severe sedimentation of salmonid-spawning and rearing habitat (Slaney et al. 1977). Prior to 1980, log drives contributed to habitat degradation on many systems, including the Stellako, Nadina and Quesnel rivers (International Pacific Salmon Fisheries Commission 1966, 1970), and to the loss of the upper Adams River sockeye (Thompson 1945). Regulations to protect streams during logging operations on public land have become stricter in recent years, but compliance has been irregular (Tripp 1994). A major watershed restoration project is underway throughout the province (Keeley and Walters 1994), and recent forest practice legislation should result in improved stream protection (Anonymous 1994). However, few large, unlogged watersheds remain, and there is much room for restoration work.

Urbanization is proceeding rapidly in the lower Fraser valley, on the east coast of Vancouver Island, and at various other areas throughout the province. Harris (1978) identified 20 historic salmon-supporting streams within the core of Vancouver that had been placed in culverts. This resulted in the complete loss of the native stocks. Similar historic detail is not available for other urban centers in the province, but the losses are likely to be similar. In addition to these direct habitat losses, urbanization results in changes in stream and riparian habitats; in pollution from sewage, stormwater, and landfills; and changes in water tables or run-off patterns. Coho and cutthroat that rear in small, low-gradient streams are particularly susceptible to these development effects (Trotter et al. 1993). Development of community water supplies has led to losses of anadromous fish habitat in the Capilano, Coquitlam, and Sooke rivers. Chloramination of some community water supplies may lead to additional losses (Nikl 1994).

Impoundments: The major river systems that support anadromous salmon in British Columbia do not have mainstem dams. However, dams on the Columbia River in the United States led to extirpation of chinook, sockeye, and steelhead stocks in the Canadian portion of the Columbia basin (Sholz et al. 1985). Unfortunately, these stocks were not well documented, and the extent of the losses is unknown. Dam construction for hydroelectric development also led to stock losses in the Alouette, Bridge, and Coquitlam rivers (Hirst 1991) as well as the Okanagan River (Fulton 1970). At other sites, including the Cayoosh, Cheakamus, Jordan, Middle Shuswap, Nechako, Puntledge, Seton, Stave, and Yukon rivers, conflicts between water requirements for power and fisheries uses have resulted in stock depressions and the need for extensive mitigation programs.

Not all dams in British Columbia are for hydropower. On the north coast, the Surf River was dammed in 1918 to provide power and transportation for mine

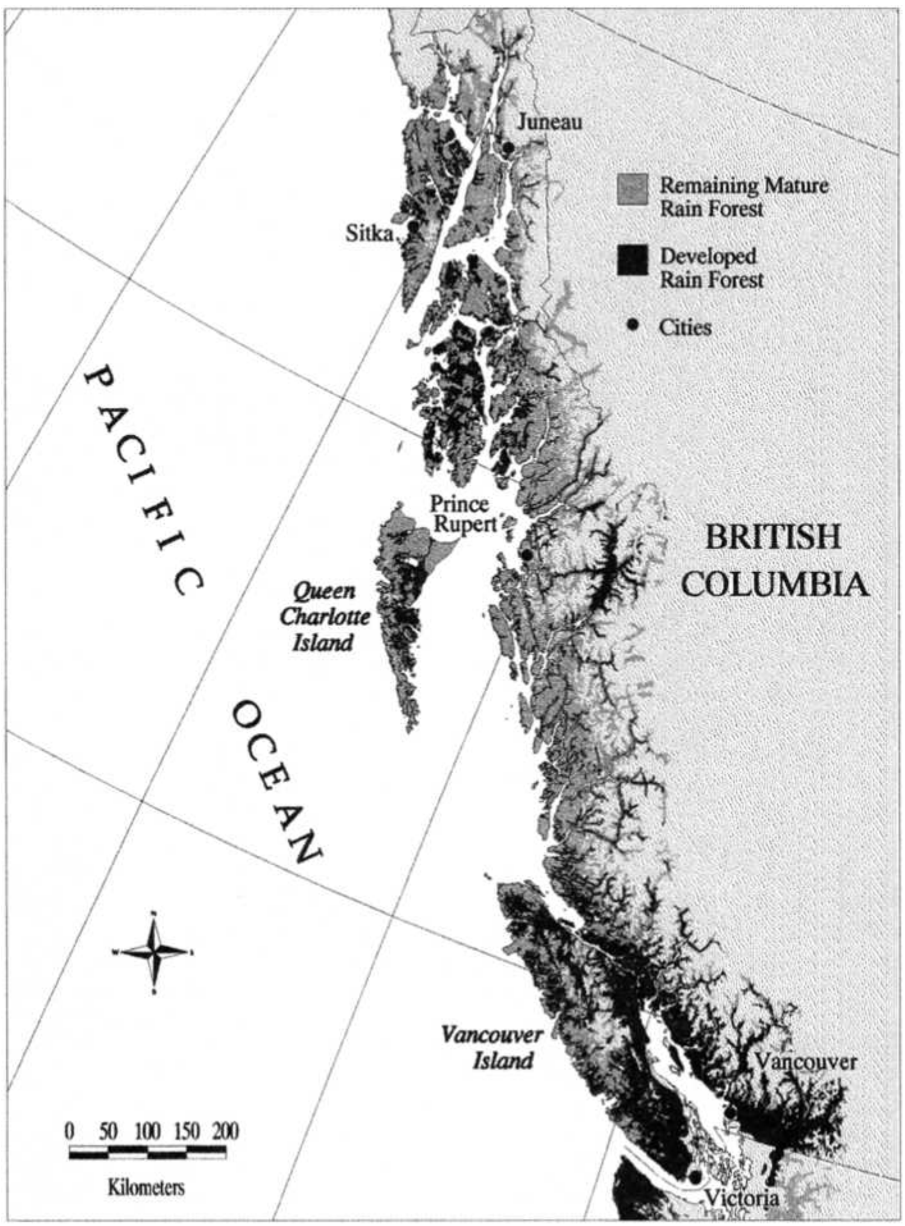

Figure 5 identifies the current status of forest cover removal and disturbance as an indicator of salmonid habitat disruption in coastal British Columbia. *Source: Interrain Pacific, Portland, Oregon.*

development and resulted in destruction of a sockeye stock (Joe Fielden, DFO, personal communication). Further south, impoundments for community water supplies on Capilano and Coquitlam systems also have led to stock losses. In addition, salmon stocks in the Sooke River, which provides water to the Victoria area of southwest Vancouver Island, are constrained by low water levels in summer.

Dikes, dredging, and fills: In the Lower Fraser River, dyking and filling have transformed 80% of the wetlands, including intertidal and shallow subtidal zones, into agricultural and industrial land (Environment Canada 1986). Dikes now exclude juvenile salmon from former habitats in many small tributaries. Examples include the Salmon River at Langley, where flood gates now block stream flow during spring and early summer while the river is pumped out to the Fraser River. This process results in a 20% loss in emigrating coho smolts (Paish and Associates 1981). Further up the Fraser River, the draining of Sumas Lake from 1919 to 1923 resulted in the loss of 12,000 ha of fish habitat, including the shallow lake and its associated wetlands (Henderson 1991). Estuary destruction or degradation through dyking, log storage, and other industrial uses also has been common in other coastal areas of the province, particularly on the Squamish River, the east coast of Vancouver Island, and the heads of the larger inlets. Maintenance dredging in the shipping channels of the Lower Fraser River has resulted in numerous juvenile salmon mortalities (Tutty 1976). This threat is now much reduced, thanks to guidelines developed by DFO in 1986.

Birtwell et al. (1988) suggested that river bank armoring (rip rapping) to protect riparian lands is a major source of habitat disruption in British Columbia. They reported 50 such installations on the 87-km Coldwater River alone.

Mining: There are few records of fish habitat issues resulting from nineteenth-century gold rushes on the Fraser and Cariboo rivers. However, an 1899 dam on the Quesnel River, which stored water for placer mining, blocked fish passage, and almost resulted in the loss of the Horsefly River sockeye stocks, which were at that time the largest on the Fraser River (Babcock 1903). More recently, mine effluents have contributed to stock depressions at several locations in British Columbia, including the Tsolum River on eastern Vancouver Island and the Coquihalla River on the Lower Fraser system (Birtwell et al. 1988). In Yukon, mining effluents have raised concerns about habitat degradation and reduced salmon survivals such that major research and mitigation programs have been necessary to ensure protection of native salmonid stocks (Anonymous 1993a).

Agriculture: In British Columbia, agriculture is limited by land capability, only 3% of the land is suitable for crops, and a further 10% is rangeland. These activities, and their potential impacts on salmon stocks, are limited to subbasins of the Fraser River, the Lower Fraser valley, and the Okanagan valley as well as the east coast of Vancouver Island and the Bulkley valley. In the Lower Fraser valley and eastern Vancouver Island, problems include channelization (Schubert 1982), pesticides (Wan 1989), and declining groundwater levels. The same problems exist in the Thompson/Nicola area, although water extraction and damage to riparian communities in rangeland areas may have larger impacts on local salmon stocks (Birtwell et al. 1988).

Road and rail construction: The largest single habitat threat to B.C salmon stocks, the 1913 Hells Gate slide, as discussed earlier, was precipitated by railroad construction in the Fraser Canyon (Thompson 1945; Ricker 1987, 1989). Elsewhere in the province, impacts have been less dramatic. However, rugged terrain forces rail lines and highways to closely parallel water courses in many areas. As a result, channelization, bank stabilization, and impassable culverts have destroyed, degraded, or alienated extensive habitat. These problems have declined with increased enforcement of the Fisheries Act and "no-net-loss" guidelines for fish habitat protection (DFO 1986). In addition to habitat loss, the proximity of road and rail lines poses a risk of toxic spills, although improvements in hazardous materials handling regulations have recently reduced this risk.

Effluents: The Fraser River, which drains almost a quarter of British Columbia, carries the effluents generated by 66% of the population, most of whom are concentrated along the lower 100 km of the river (Dorcey 1991). Wastewaters from communities around Georgia Strait pose additional fish habitat problems, as do point sources such as pulp mills in other locations along the coast.

Water quality in the Fraser River is good relative to the St. Lawrence River and lower Great Lakes (Hall et al. 1991), but industrial and municipal effluents entering the river have increased markedly during the last 30 years (Servizi 1989). Unsafe conditions for fish and altered benthic communities have been detected in dilution zones of both inland and tidal portions of the basin (Bothwell 1992; Perrin and Bothwell 1992). In addition, various contaminants have been reported in resident fish from the lower river (FREMP 1990; Rogers et al. 1992). However, Servizi (1989) found no indication of contaminant impacts on migrating sockeye and pink salmon or on the incubation success of mainstem-spawning pink salmon, although localized fish kills resulting from spills and toxic wastewaters have been reported in all parts of the watershed. Servizi (1989) also suggested that juvenile chinook may be drawn to potentially lethal dilution zones by warmer water temperatures, particularly in winter, although the potential losses resulting from this attraction are unknown. Juvenile chinook losses also were observed near the former Iona Island sewage outfall (Birtwell et al. 1983). Coho streams appear to be particularly prone to water contamination in lower Fraser tributaries (Petersen and Lewynsky 1985; Wan 1989). Thus, while no evidence can be found to confirm stock loss due to pollution, there are numerous areas for concern. We anticipate water quality improvements following the recent tightening of effluent standards for pulpmills (particularly for chlorinated dioxins and furans), but numerous sewage and nonpoint problems remain (Anonymous 1995).

Local water quality degradation from industrial effluents has also been identified as contributing to fish stress, migration delays, and possible mortalities in coastal locations such as Alberni and Neroutsos inlets (Tully 1949; Morris and Leaney 1980; Birtwell 1989).

(2) Overutilization.

The concept of regulation to ensure adequate escapement and preservation of individual stocks has been at the base of B.C. harvest management since the turn of the century (Babcock 1903). It has proved a difficult goal. While the rebuilding trends in coastwide chinook salmon have resulted from management and stock conservation actions initiated through the U.S.-Canada Salmon Treaty prior to 1994, the mixed-stock nature of many coastal fisheries—as well as steady increases in both the effort and effectiveness of commercial, sport, and aboriginal fishers—continue to threaten many of British Columbia's weaker salmon stocks.

Current fisheries management attempts to focus harvest effort on stocks at times and locations intended to minimize the bycatch of other stocks or species (Henderson 1991), but it is difficult to separate fishing effort from weak stocks. Return timing of large stocks that can withstand large harvests usually overlaps with other species and numerous smaller, less-productive stocks that cannot withstand high harvest rates. Until driftnet fisheries were banned, mixed stock harvest began as bycatch in drift net fisheries during ocean residence (Northridge 1991). Now, outside troll fisheries harvest many stocks as they approach land off northern British Columbia and southeastern Alaska (Henderson 1991). The problem persists further inshore. The traditional river mouth fishery on the Skeena system targeted Babine Lake sockeye but also harvested sockeye from Alastair, Lakelse, Kitsumkalum, Kitwanga, Bulkley, Kispiox, Bear, and Johanson lakes as well as numerous smaller sockeye stocks and other species (McDonald 1981; Sprout and Kadowaki 1987). The timing and net design of the Skeena fishery have been modified extensively in recent years to minimize steelhead bycatch, yet a basic conflict remains. Similar problems are associated with the sockeye fisheries of the Fraser system, and current stock rebuilding plans designed to increase returns of Fraser River sockeye will increase the disparity between weak and strong stocks (Henderson 1991). Other problems of B.C. fisheries include Johnstone Strait nets, Juan de Fuca nets, and the Georgia Strait sport fishery.

The problem is further complicated by a hierarchy of user groups. Allocations for stock conservation are placed above those for the aboriginal fisheries. Sport and commercial allocations, with various subdivisions, then follow. Unfortunately, the commercial allocations are taken in marine waters, well before the inland aboriginal fisheries, and some contention is inevitable. In recent years extensive efforts have been made to adjust fishing times, locations, and techniques to minimize bycatch, but some losses continue.

The interception of steelhead by commercial fisheries targeted on other species is an example of the bycatch problem. Efforts to monitor steelhead interception and adjust fishing patterns to minimize the impact have been underway since 1963 (Andrews and McSheffrey 1976; Tautz et al. 1992). The problem is that steelhead stocks are typically small with low productivity, yet their migration coincides with other commercial species that are the subject of enhancement or stock rebuilding and can be harvested at higher rates. In the Skeena system, steelhead stocks are chronically depressed. An escapement of 26,000 is required for maximum sustained yield (Tautz et al. 1992), but test fishing results from the mouth of the river indicate the target was met only three times between 1981 and 1990 (Pacific Salmon Commission 1991). However, those results do not account for additional in-stream mortalities resulting from aboriginal and sport fisheries as well as poaching and natural losses.

In addition to the habitat problems associated with urbanization, increased population densities have been accompanied by increased sport fisheries in Georgia Strait, Barkley Sound, and other places throughout the province. The Georgia Strait sport fishery accounts for 75% of the recreational catch of chinook and coho in the entire province (Henderson 1991) and results in harvest rates for local wild stocks that are thought to be 10% above maximum sustainable yield (Kadowaki et al. 1995). Freshwater angling of steelhead and sea-run cutthroat has been strictly controlled recently. In southern British Columbia, all wild trout captured in streams or tidal waters must be released (MELP 1994; DFO 1995). Additional restrictions apply to individual streams. However, in-stream mortalities are difficult to eradicate completely. Catch-and-release fisheries still result in small but finite hooking mortality (Hooton 1987).

(3) Disease.

Fish diseases are widespread in B.C. salmon and have been reported from cultured, feral, and wild populations (Hoskins et al. 1976). Scientists have observed severe mortalities due to a bacterial disease *(Flexibacter columnaris)* in sockeye stocks in the Horsefly, Chilko, and Stellako rivers, particularly during periods of warm water temperatures (Colgrove and Wood 1966; Cooper 1973; Williams 1973). However, incidents large enough to result in measurable declines of wild populations are rarely documented. Nonetheless, observation of a 40% reduction in egg-to-fry survival of 1972 brood Chilko Lake sockeye after an infectious hepatic necrosis epizootic (Williams and Amend 1976) suggests it is possible. The DFO monitors disease problems in wild and cultured stocks and maintains a record of pathogen observations. No incidents of wild stock extinctions resulting from disease have been recorded (D. Kieser, DFO, personal communication).

(4) Other negative interactions.

In British Columbia, little risk of stock loss through introgression with nonnative hatchery fish appears to exist, although some stocks may be modified as a result of hatchery operations. Hatchery operations began in British Columbia in 1884 (Aro 1979). The program was accompanied by widespread transplants of sockeye eggs and eggs of some other species, but low survivals led to cancellation of the program in 1937, and a very limited amount of introgression is thought to have resulted. When salmon hatchery operations resumed in the 1960s, federal/provincial guidelines were introduced that prohibited transfers of nonnative stock between watersheds unless the native stock of the receiving watershed was extinct. As a result, few documented instances of extinction resulting from hatchery introductions exist. The Chilliwack River provides an example of a more subtle change. While hatchery chum and coho are all derived from native stock, it is no longer possible to distinguish between the wild and hatchery populations (J. Buxton, DFO, personal communication). Numerous stocks, including the Capilano River chinook, do not represent the native stock but a more recent introduction. The provincial government has followed a similar policy with steelhead and cutthroat. These policies reduce introgression risk, but without careful management, a risk remains of interspecies interactions and loss of unenhanced species (Slaney et al. 1985). Trotter et al. (1993) suggest that cutthroat may be particularly susceptible to competition from hatchery stock coho and steelhead. Although coho and steelhead are stocked into far more streams than cutthroat, no information was available on the extent or significance of this problem in British Columbia.

In the last decade fish farms using seapen facilities to rear exotic species, particularly Atlantic salmon and domesticated strains of chinook and coho, have proliferated. Quarantine and transport of such fish are strictly regulated, and further safeguards are under investigation (Anonymous 1993b). Questions have also been raised about their viability in the wild since concerted 1911–1934 efforts to establish Atlantic salmon in the Cowichan River were unsuccessful (Neave 1949). Still, Atlantic salmon from farm sources are being recovered in increasing numbers from both marine and freshwater B.C. environments, particularly around northern Vancouver Island, Johnstone Straits, and the Lower Fraser River (Thomson and McKinnel 1994). In November 1994, a tanker truck spill resulted in the release of 20,000 Atlantic salmon presmolts to Menzies Creek on Vancouver Island (P. Law, MELP, personal communication). After the cleanup, 5,000 fish were still missing. The incident is unlikely to result in establishment of a feral population, but it does illustrate the risk. A public review of the problems associated with aquaculture is underway.

(5) Other natural factors.

The extinction of salmon stocks from natural factors appears to occur at a much slower rate than losses due to human intervention. In the short term, documented losses from natural factors are rare. A natural cause may be deduced indirectly by the 1994 decline of lake spawning sockeye in Kennedy Lake from 100,000 to 3 in the absence of any fishery. However, major environmental perturbations during the last 50 years such as the Babine River slide (Godfrey et al. 1954), overturn of anoxic Nitinat Lake (Fedorenko et al. 1979), and reduced ocean survivals following El Niño events (Ashton et al. 1985; Fulton and LeBrasseur 1985) have reduced population sizes but do not by themselves appear to have resulted in wild stock extinctions. The flood resulting from collapse of a glacial dam on the Noeick River (McGivney et al. 1985) has placed some stocks at high risk of extinction, but the decline is slow. Ten years after the event the stocks are still present.

In the longer term, natural factors do appear to result in stock losses. For example, throughout British Columbia kokanee stocks exist in lakes that are no longer accessible to anadromous fish. If these fish represent individual modifications of the anadromous form (Ricker 1940; Foote et al. 1989), the currently isolated kokanee represent anadromous sockeye stocks that have become extinct as a result of post-glacial rebound or changes in drainage patterns. It would follow that at least a portion of these systems also supported other anadromous salmon species. In the future, natural events such as changes in ocean conditions offshore (Beamish and Bouillon 1993) and global warming (Henderson et al. 1992; Levy 1992) may reduce salmonid survivals and eventually result in stock losses.

Conclusions

In addition to their economic and biodiversity values, native salmon stocks serve as valuable "canaries" indicating the health of our aquatic environments. Protecting them is an important step in preserving our heritage. Further work is needed to extend this status assessment. More importantly, institutional and management changes are needed to ensure the survival of our many small salmon stocks.

Completing a comprehensive identification and assessment of salmon stocks in the B.C. and Yukon areas is a massive undertaking. Our project serves as a start to the work and is sufficient for an overview-level summary of salmon status. However, we were able to apply status evaluations to only 57% of the stock list (Figure 4). Ongoing work in this area is necessary if the full dimensions of the resource are to be known. Some of the steps in this process should include the following:

(a) A stratified inventory sampling system to assess diversity issues should be undertaken. Given continuing resource limitations at all levels of the public sector, some means of systematically sampling small populations in different areas of British Columbia and Yukon should be developed. In this way the status of weak stocks can be better understood without massive expenditure.

(b) Inventory calibration studies should be implemented. Detailed sampling in representative areas would facilitate estimates of the actual status of the many stocks that could not be assessed in our project.

(c) Work on a more reliable basis for characterizing stock status is needed. This should include not only an analysis of the difference in risk associated with various species and life history strategies, but analysis of the differences in the persistence dynamics of large and small stocks.

SUMMARY

At the species aggregate level, salmon stocks in British Columbia and Yukon, other than coho, appear to be either stable or increasing. However, assessments at the aggregate level commonly mask the degree of success achieved in maintaining biodiversity. At the individual stock level, there is cause for serious concern. We identified 9,663 stocks. Status classifications were possible for 5,487 (57%) of these. Most were unthreatened. However, 624 (6.4%) stocks fell into the high risk of extinction category; 78 (0.8%) were considered in moderate risk; and a further 230 (2.3%) were considered to be of special concern. The list also included 142 (1.4%) stocks known to have been extirpated in this century. The status of 4,172 (43%) of the stocks could not be determined. Due to their small size, these stocks are not of great commercial importance but are important to the maintenance of salmon diversity. There remains a large number of stocks of which little is known (e.g., most sea-run cutthroat stocks).

For 920 stocks the mean escapement for the last decade has been 0. These were not classified as extinctions because inspections could have been made at unsuitable times or places, and the stocks may still exist. However, enough stocks exist in this category to suggest that both the high-risk and extinct categories could be much larger than the our current study suggests.

We found few instances where an extinction and risk can be attributed to a single cause. In most instances, several factors appear to be at work. However, the largest portion of the 142 extinctions we note resulted from urbanization and hydropower development. More salmon populations were likely lost before record-keeping started.

Local adaptation in salmon stocks is an ongoing process that is naturally accompanied by local extinctions as environmental conditions change throughout time. However, in British Columbia, these losses appear to have occurred at a much higher rate as a result of human activity.

(d) The stock extinctions noted in this project are probably a small fraction of those lost since European contact. Many stocks, including those in the upper Columbia River, have been destroyed in the last 60 years. Some effort should be made to document these stocks while the people who remember them are alive. Information from First Nations peoples regarding historically fished stocks and sites would be particularly helpful in this regard. Information on earlier stock extinctions may also be gleaned from sources such as records of the fishing activities that accompanied the fur trade.

(e) Habitat preservation is a critical link in preserving native salmon stocks. While the "no-net-loss" policy and new conservation initiatives may be working to preserve habitats in rural areas, more effort is needed to halt habitat degradation and loss in urban areas. In some rapidly urbanizing areas of the province, small populations are being lost before they can be identified.

(f) Finally, some changes in fisheries management approaches appear critical. Almost a century after identifying the need to ensure adequate spawning escapement for every salmon stock, this goal still eludes us. Continued work to reduce mixed-stock fisheries is needed. Many small stocks that are now passively managed may require more dynamic measures to ensure adequate escapements.

Acknowledgments

Many people and agencies contributed both time and information to this project. It would not have been possible without their support, and we thank them profusely. In particular, we want to thank Pete Bisson, Bryan Hebden, Pam McClelland, Ted Perry, and Marvin Rosenau for their helpful reviews and encouragement. We also thank Stephanie Eagen for her many hours in libraries and dusty file rooms. Funding for the project was provided by a grant from The Pew Charitable Trusts of Philadelphia to the American Fisheries Society.

References

Andrews, T. R., and **H. M. McSheffrey.** 1976. Commercial interceptions of steelhead trout stocks in British Columbia: a preliminary review. B.C. Marine Resources Branch, Fisheries Management Report No. 1, Victoria.

Anonymous. 1992. Coho planning process and recommendations. Canada Department of Fisheries and Oceans (DFO), Coho Steering Committee, Vancouver, BC.

———. 1993a. The Yukon placer authorization and supporting documents. Government of Canada, Ottawa, ON.

———. 1993b. Wild/farmed salmonid interactions: review of potential impacts and recommended action. BC Ministry of Agriculture, Fish, and Food and Ministry of Environment, Lands and Parks, Victoria.

———. 1994. British Columbia forest practices code. BC Ministry of Forestry and Ministry of Environment, Lands and Parks, Victoria.

———. 1995. British Columbia's pulp mills: effluent status report-1994 update. BC Ministry of Environment, Lands and Parks, Victoria.

Aro, K. V. 1979. Transfer of eggs and young of Pacific salmon within British Columbia. DFO, Fisheries and Marine Service Tech. Rep. 861, Vancouver, BC.

Ashton, H. J., V. Haist, and **D. M. Ware.** 1985. Observations on abundance and diet of Pacific mackerel (*Scomber japonicus*) caught off the west coast of Vancouver Island, September 1984. Can. Tech. Rept. Fish. Aquat. Sci. 1,394.

Babcock, J. P. 1903. Report of the fisheries commissioner for British Columbia for the year 1902. DFO, Fisheries Department, Victoria, BC.

Beamish, R. J., and **D. R. Bouillon.** 1993. Pacific salmon production trends in relation to climate. Can. J. Fish. Aquat. Sci. 50:1,002–1,016.

Birtwell, I. K. 1989. Comments on the sensitivity of salmonids to reduced levels of dissolved oxygen and to pulp mill pollution in Neroutsos Inlet, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1,695.

Birtwell, I. K., C. D. Levings, J. S. MacDonald, and **I. H. Rogers.** 1988. A review of fish habitat issues in the Fraser River system. Water Pollut. Res. J. Can. 23:1–30.

Birtwell, I. K., G. L. Greer, M. D. Nassichuk, and **I. H. Rogers.** 1983. Studies on the impact of municipal sewage discharged onto an intertidal area within the Fraser River estuary, British Columbia. Can. Tech. Rept. Fish. Aquat. Sci. 1,170.

Bothwell, M. L. 1992. Eutrophication of rivers by nutrients in treated kraft mill effluent. Water Pollut. Res. J. Can. 27: 447–472.

Campton, D. E., and **F. M. Utter.** 1987. Genetic structure of anadromous cutthroat trout (*Salmo clarki clarki*) populations in the Puget Sound area: evidence for restricted gene flow. Can. J. Fish. Aquat. Sci. 44:573–582.

Colgrove, D. J., and **J. W. Wood.** 1966. Occurrence and control of *Chondrococcus columnaris* as related to Fraser River sockeye salmon. Progress Report 15. International Pacific Salmon Fisheries Commission, New Westminster, BC.

Cooper, A. C. 1973. Temperature control during sockeye spawning period in McKinley Creek in 1969. Progress Report 27, Part 1. International Pacific Salmon Fisheries Commission, New Westminster, BC.

DFO (Department of Fisheries and Oceans). 1986. Policy for the management of fish habitat, Ottawa. Cat. no. Fs 2398/1986E, Ottawa, ON.

———. 1994. Lost streams of the lower Fraser River. Fraser River Action Plan, Vancouver, BC.

———. 1995. British Columbia tidal waters sportfishing guide 1995–1996. Cat. No. Fs 1-43/1996E, Ottawa, ON.

Dorcey, A. H. J. 1991. Water in the sustainable development of the Fraser River basin. Pages 3–18 *in* A. H. J. Dorcey and J. R. Griggs. eds. Water in sustainable development: exploring our common future in the Fraser River basin. Westwater Research Centre, University of British Columbia, Vancouver.

Environment Canada. 1986. Fact sheet on wetlands in Canada: a valuable resource. Cat. no. En 73-6/86-4E, Lands Directorate, Ottawa, ON.

Fedorenko, A. L., F. J. Fraser, and **D. T. Lightly.** 1979. A limnological and salmonid resource study of Nitinat Lake: 1975–1977. Environment Canada, Fisheries and Marine Service Tech. Rep. 839, Victoria, BC.

Foote, C. J., C. C. Wood, and **R. E. Withler.** 1989. Biochemical genetic comparison of sockeye salmon and kokanee, the anadromous and nonanadromous forms of *Oncorhynchus nerka*. Can. J. Fish. Aquat. Sci. 46:49–158.

FREMP (Fraser River Estuary Management

Program). 1990. Status report on water quality in the Fraser River estuary. Standing Committee on the Fraser River Estuary Water Quality Plan, New Westminster, BC.

Fulton, J. D. and **R. J. LeBrasseur.** 1985. Interannular shifting of the subarctic boundary and some of the biotic effects on juvenile salmonids. Pages 237–247 *in* W. S. Wooster and D. L. Fluharty, editors. El Niño north: Niño effects on the eastern subarctic Pacific Ocean. Washington Sea Grant Program. University of Washington, Seattle.

Fulton, L. A. 1970. Spawning areas and abundance of steelhead trout and coho, sockeye, and chum salmon in the Columbia River basin—past and present. U.S. Department of Commerce, National Marine Fisheries Service, Spec. Scientific Rep.—Fisheries 618, Washington, DC.

Godfrey, H., W. R. Hourston, J. W. Stokes, and **F. C. Withler.** 1954. Effects of a rock slide on Babine River salmon. Fish. Res. Bd. Canada Bull. 101.

Hall, K. J., H. Schreier, and **S. J. Brown.** 1991. Water quality in the Fraser River Basin. Pages 41–75 *in* A. H. J. Dorcey, and J. R. Griggs, eds. Water in sustainable development: exploring our common future in the Fraser River basin. Westwater Research Centre, University of British Columbia, Vancouver.

Harris, G. 1978. The salmon and trout streams of Vancouver. Waters: J. Vancouver Aquarium 3:4–32.

Hartman, G. F., and **J. C. Scrivener.** 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Can. Bull. Fish. Aquat. Sci. 223.

Hatfield Consultants, Ltd. 1996. Strait of Georgia fisheries sustainability review. Vancouver, BC.

Healey, M. C. 1982. Catch, escapement, and stock recruitment for British Columbia chinook salmon since 1951. Can. Tech. Rept. Fish. Aquat. Sci. 1,107.

Henderson, M. A. 1991. Sustainable development of the Pacific salmon resources in the Fraser River basin. Pages 133–154 *in* A. H. J. Dorcey, ed. Perspectives on sustainable development in water management: towards agreement in the Fraser River basin. Westwater Research Centre, University of British Columbia, Vancouver.

Henderson, M. A., D. A. Levy, and **J. S. Stockner.** 1992. Probable consequences of climate change on freshwater production of Adams River sockeye salmon (*Oncorhynchus nerka*). GeoJournal 28:51–59.

Hirst, S. M. 1991. Impacts of the operation of existing hydroelectric developments on fishery resources in British Columbia. Can. MS Rept. Fish. Aquat. Sci. 2,093.

Holtby, L. B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 45:502–515.

Hooton, R. S. 1987. Catch and release as a management strategy for steelhead in British Columbia. Pages 143–156 *in* R. A. Barnhart and T. D. Roelefs, eds. Catch-and-release fishing: a decade of experience. Proc. National Sports Fishing Symposium, Humboldt State University, Arcata, CA.

Hoskins, G. E., G. R. Bell, and **E. P. T. Evelyn.** 1976. The occurrence, distribution, and significance of infectious diseases and neoplasms observed in fish in the Pacific Region up to the end of 1974. Environment Canada, Fisheries and Marine Service Tech. Rep. 609.

Irvine, J. R., and **T. C. Nelson.** 1995. Proceedings of the 1994 salmon escapement workshop and an annotated bibliography on escapement estimation techniques. Can. Tech. Rept. Fish. Aquat. Sci. 2,305.

International Pacific Salmon Fisheries Commission. 1966. Effects of log driving on the salmon and trout populations of the Stellako River. New Westminster, BC.

———. 1970. Proposed artificial spawning channel for Nadina River sockeye salmon. New Westminster, BC.

Johnston, N. T., J. R. Irvine, and **C. J. Perrin.** 1986. A comparative evaluation of fence count, mark-recapture, and Bendix sonar estimates of salmon escapements in the Keogh River, a variable flow coastal B.C. stream. Can. Tech. Rep. Fish. Aquat. Sci. 1,453.

Kadowaki, R., J. Arvin, B. Holtby, N. Schubert, R. Simpson, S. Bailey, and **C. Cross.** 1995. Assessment of strait of Georgia coho salmon stocks including the Fraser River. Pages 177–187 *in* J. Rice, R. Humphreys, L. Richards, R. Kadowaki, D. Welch, M. Stocker, B. Turris, G. McFarlane, F. Dickson, and D. Ware, eds. Pacific Stock Assessment Review Committee annual report for 1994. Can. MS. Rept. Fish. Aquat. Sci. 2,318.

Keeley, E. R., and **C. J. Walters.** 1994. The British Columbia watershed restoration program: summary of the experimental design, monitoring, and restoration techniques workshop. Watershed Restoration Management Report no. 1. BC Ministry of Environment, Lands and Parks and Ministry of Forests, Victoria.

Larkin, P. A. 1972. The stock concept and management of Pacific salmon. Pages 11–15 *in* R. C. Simon and P. A. Larkin, eds. The stock concept in Pacific salmon. H. R. MacMillan lectures in fisheries, University of British Columbia, Vancouver.

Levy, D. A. 1992. Potential impacts of global warming on salmon production in the Fraser River watershed. Can. Tech. Rept. Fish. Aquat. Sci. 1,889.

Lyons, C. 1969. Salmon: our heritage. British Columbia Packers Ltd., Vancouver.

Mace, G. M., and **R. Lande.** 1991. Assessing extinction threats: towards a reevaluation of IUCN threatened species categories. Conserv. Biol. 5:148–157.

McDonald, J. 1981. The stock concept and its application to British Columbia salmon. Can. J. Fish. Aquat. Sci. 38:1,657–1,664.

MacDonald, J. S., J. C. Scrivener, and **G. Smith.** 1992. The Stuart-Takla fisheries/forestry interaction project: study description and design. Can. Tech. Rept. Fish. Aquat. Sci. 1,899.

McGivney, K. K., G. J. Holowatiuk, and **P. R. Murray.** 1985. South Bentinck Arm adult salmonid reconnaissance program. Report of Envirocon Limited to Department of Fisheries and Oceans,Vancouver, BC.

McNairnay, H. R. 1987. BC16, Annual report of salmon stream and spawning grounds: an historical review. Report to Department of Fisheries and Oceans, Vancouver, BC.

MELP (Ministry of Environment, Lands and Parks). 1994. Freshwater fishing regulations synopsis. Victoria, BC.

Morris, S., and **A. J. Leaney.** 1980. The Somass River estuary, status of environmental knowledge to 1980. Environment Canada, Special Estuary Series 9. West Vancouver, BC.

Neave, F. 1949. Game fish populations of the Cowichan River. Fish. Res. Bd. Canada Bull. 84.

Nehlsen, W., J. E. Williams, and **J. A. Lichatowich.** 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and

Washington. Fisheries 16(2):4–21.
Nikl, L. 1994. Environmental impacts of chloramine disinfection of drinking water. Pages 25–26 *in* Proceedings of the 1994 seminar on environmental quality and research. Fraser River Estuary Management Program, Tech. Rept. WQWM 93-11. New Westminster, BC.
NMFS (National Marine Fisheries Service). 1980. Policy position papers for the consideration of Columbia River salmon under the Endangered Species Act. Paper #2, Biological thresholds of endangerment. National Marine Fisheries Service, Seattle, WA.
Northcote, T. G., and **D. Y. Atagi.** 1996. Pacific salmon abundance trends in the Fraser River watershed compared with other British Columbia systems. *In* D. J. Strouder, P. A. Bisson, and R. N. Naiman, eds. Pacific salmon ecosystems: status and future options. Proc. of a symposium, Seattle, Washington, 10–12 January 1994. Chapman and Hall, New York.
Northridge, S. P. 1991. Driftnet fisheries and their impacts on non-target species: a worldwide review. Food and Agriculture Organization Fish. Tech. Paper 320, Rome.
Pacific Salmon Commission. 1991. Review of steelhead stock status, harvest patterns, enhancement and migrations in the northern boundary area. Northern Boundary Technical Committee Rept. TCNB (91)-1, Vancouver, BC.
Paish and Associates. 1981. The implementation of a co-operative watershed planning and management program for the Fraser River watershed—Langley, BC. Report to Department of Fisheries and Oceans, Vancouver, BC.
Pearse, P. H. 1982. Turning the tide: a new policy for Canada's Pacific fisheries. Final report of the Commission on Pacific Fisheries Policy. Vancouver, BC.
Perrin, C. J., and **M. L. Bothwell.** 1992. Chlorate discharges from pulp mills: an examination of effects on river algal communities. Water Pollut. Res. J. Can. 27: 473–485.
Petersen, G. R., and **V. A. Lewynsky.** 1985. Review of lower Fraser system salmon escapement, habitat conditions and exploitation rates. Report of H. Paish and Associates to Department of Fisheries and Oceans, Vancouver, BC.
Ricker, W. E. 1940. On the origin of kokanee, a fresh-water type of sockeye salmon. Trans. Royal Soc. Can. 5:121–135.
———. 1972. Hereditary and environmental factors affecting certain salmonid populations. Pages 19–160 *in* R. C. Simon and P. A. Larkin, eds. The stock concept in Pacific salmon. H. R. MacMillan Lectures in Fisheries, University of British Columbia, Vancouver.
———. 1987. Effects of the fishery and of obstacles to migration on the abundance of Fraser River sockeye salmon *(Oncorhynchus nerka).* Can. Tech. Rept. Fish. Aquat. Sci. 1,522.
———. 1989. History and present state of the odd-year pink salmon runs of the Fraser River region. Can. Tech. Rept. Fish. Aquat. Sci. 1,702.
Riddell, B. E. 1993. Spatial organization of Pacific salmon: What to conserve? Pages 23–42 *in* J. G. Cloud and G. H. Thorgaard, eds. Genetic conservation of salmonid fishes. Plenum Press, New York.
Rogers, I. H., J. S. Macdonald, and **M. Sadar.** 1992. Uptake of selected organochlorine contaminants in fishes resident in the Fraser River estuary, Vancouver, British Columbia. Water Pollut. Res. J. Can. 27:733–749.
Schubert, N. D. 1982. A bio-physical survey of thirty lower Fraser valley streams. Can. MS Rept. Fish. Aquat. Sci. 1,644.
Serbic, G. 1991. The salmon escapement database and reporting system. Can. Tech. Rept. Fish. Aquat. Sci. 1,791.
Servizi, J. A. 1989. Protecting Fraser River salmon *(Oncorhynchus* spp.) from wastewaters; an assessment. Pages 136 –153 *in* C. D. Levings, L. B. Holtby, and M. A. Henderson, ed. Proceedings of the national workshop on the effects of habitat alteration on salmonid stocks. Can. Spec. Publ. Fish. Aquat. Sci. 105.
Shirvell, C. S., and C. **Charbonneau.** 1984. Can stream indexing improve salmon escapement estimates? Pages 49-65 *in* P. E. K. Symons and M. Waldichuck, eds. Proceedings of the workshop on stream indexing for salmon escapement estimating. Can. Tech. Rept. Fish. Aquat. Sci. 1,326.
Sholz, A., K. O'Laughlin, D. Geist, D. Peone, J. Uehara, L. Fields, T. Kleist, I. Zozaya, T. Peone, and **K. Teesatuskie.** 1985. Compilation of information on salmon and steelhead total run size, catch, and hydropower-related losses in the upper Columbia River basin, above Grand Coulee Dam. Upper Columbia United Tribes Fisheries Research Center, Fish. Tech. Rep. 2.
Slaney, P. A., T. G. Halsey, and **H. A. Smith.** 1977. Some effects of forest harvesting on salmonid rearing habitat in two streams in the central interior of British Columbia. British Columbia Ministry of Environment, Fisheries Management Report 71.
Slaney, T. L., K. D. Hyatt, T. G. Northcote, and **R. J. Fielden.** In press. Extinction risk classification for anadromous salmon and trout of British Columbia and Yukon. Can. MS Rept. Fish. Aquat. Sci.
Slaney, T. L., J. D. McPhail, D. Radford, and **G. J. Birch.** 1985. Review of the effects of enhancement strategies on interactions between juvenile salmonids. Can. MS Rept. Fish. Aquat. Sci. 1,852.
Sprout, P. E., and **R. K. Kadowaki.** 1987. Managing the Skeena River sockeye salmon *(Oncorhynchus nerka)* fishery—the process and the problems. Pages 385–395 *in* H. D. Smith, L. Margolis, and C. C. Wood, eds. Sockeye salmon *(Oncorhynchus nerka)* population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.
Tautz, A. F., B. R. Ward, and **R. A. Ptolemy.** 1992. Steelhead trout productivity and stream carrying capacity for rivers of the Skeena drainage. BC Ministry of Environment, Lands and Parks, Fisheries Branch, Vancouver.
Thompson, G. G. 1991. Determining minimum viable populations under the Endangered Species Act. U.S. Department of Commerce, National Marine Fisheries Service, Tech. Mem. NFSF/NWC-198.
Thompson, W. F. 1945. Effect of the obstruction at Hell's Gate on the sockeye salmon of the Fraser River. International Pacific Salmon Fisheries Commission. Bull. 1. New Westminster, BC.
Thomson, A. J., and **S. McKinnel.** 1994. Summary of reported Atlantic salmon *(Salmo salar)* catches and sitings in British Columbia and adjacent waters in 1993. Can. MS Rept. Fish. Aquat. Sci. 2,246.
Tripp, D. B. 1994. The use and effectiveness of the Coastal Fisheries Forestry Guidelines in selected forest districts of coastal British Columbia. Report to BC Ministry of Environment, Lands and Parks, Victoria.
Tripp, D. B., and **V. A. Poulin.** 1992. The effects of logging and mass wasting on juvenile salmonid populations in streams on the Queen Charlotte Islands. Land Management Report 80.

B.C. Ministry of Forests, Victoria.

Trotter, P. C. 1989. Coastal cutthroat trout: a life history compendium. Trans. Am. Fish. Soc. 118:463–473.

Trotter, P. C., P. A. Bisson, and **B. Fransen.** 1993. Status and plight of the sea-run cutthroat trout. Pages 203–212 *in* J. G. Cloud and G.H. Thorgaard, eds. Genetic conservation of salmonid fishes. Plenum Press, New York.

Tschaplinski, P. J., and **K. D. Hyatt.** 1991. A comparison of population assessment methods employed to estimate the abundance of sockeye salmon (*Oncorhynchus nerka*) returning to Henderson Lake, Vancouver Island, during 1989. Can. Tech. Rept. Fish. Aquatic Sci. 1,798.

Tully, J. P. 1949. Oceanography and prediction of pulpmill pollution in Alberni Inlet. Fish. Res. Bd. Canada Bull. 83.

Tutty, B. 1976. Assessment of techniques used to quantify salmon smolt entrainment by a hydraulic suction hopper dredge in the Fraser River estuary. Environment Canada, Fisheries and Marine Service, Habitat Protection Directorate. Tech. Rep. Series PAC/T-76-16, Vancouver, BC.

Waldichuck, M. 1984. Chairman's summary. Pages ix–xv *in* P. E. K Symons and M. Waldichuck, eds. Proceedings of a workshop on stream indexing for salmon escapement estimation, West Vancouver, British Columbia, 2–3 February 1984. Can. Tech. Rept. Fish. Aquat. Sci. 1,326.

Walters, C. J. 1995. Fish on the line: the future of Pacific fisheries. David Suzuki Foundation, Vancouver, BC.

Walters, C. J., and **P. Cahoon.** 1985. Evidence of decreasing spatial diversity in British Columbia salmon stocks. Can. J. Fish. Aquat. Sci. 42:1,033–1,037.

Wan, M. T. 1989. Levels of selected pesticides from farm ditches leading to rivers in the lower mainland of British Columbia. J. Environ. Sci. Health B24: 183–203.

Ward, B. R., and **J. C. Wightman.** 1989. Monitoring steelhead trout at the Keogh River as an index of stock status and smolt-to-adult survival: correlations with other data sources. BC Ministry of Environment. Fisheries Management Report 95, Vancouver.

West, C. J ., and **J. C. Mason.** 1987. Evaluation of sockeye salmon *(Oncorhynchus nerka)* production from the Babine Lake Development Project. Pages 176–190 *in* H. D. Smith and C. C. Wood, eds. Sockeye salmon *(Oncorhynchus nerka)* biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Williams, I. V. 1973. Investigation of the pre-spawning mortality of sockeye in the Horsefly River and McKinley Creek in 1969. International Pacific Salmon Fisheries Commission, Progress Report 27, Part II. New Westminster, BC.

Williams, I. V., and **D. F. Amend.** 1976. A natural epizootic of infectious hematopoetic necrosis in fry of sockeye salmon (*Oncorhynchus nerka*) at Chilko Lake, British Columbia. J. Fish. Res. Bd. Canada 33:1,564–1,567.