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ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX I: PACIFIC SALMON

Authors:
Kim Hyatt[1], M.S. Johannes[1], and Margot Stockwell[1]

Edited by:
B.G. Lucas, S. Verrin, and R. Brown

[1]Fisheries & Oceans Canada
Pacific Biological Station
Nanaimo, BC V9T 6N7

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1.0 INTRODUCTION

1.1 General Biology and Importance

Pacific salmon (genus *Oncorhynchus*) are an important biological, cultural, and economic resource of countries of the North Pacific rim. The range of salmon extends from southern California, north along the Canadian and Alaskan coasts to rivers draining into the Arctic Ocean, and then southward along Asian coastal areas of Russia, Japan, and Korea (Groot and Margolis 1991). There are 8 species of Pacific salmon 6 of which (*i.e.,* sockeye, pink, chum, chinook, coho, and steelhead salmon) are commonly found on the west coast of North America. The fossil record suggests that ancestral Pacific salmon have been around for at least 18 million years and the several distinctive species we recognize today have been around for at least 6 million years (Augerot *et al.* 2005).

At the most general level, all Pacific salmon exhibit similar life cycles: they spawn in gravel beds in rivers, streams or along lake shores. They generally migrate to sea as juvenile forms after a period of freshwater life varying from days to years (Figure I.0); an additional period of several months to years is usually spent at sea feeding and rearing to the adult stage. Salmon are widely distributed over the North Pacific Ocean and Bering Sea during the marine phase of their life history (Hartt and Dell 1986). Populations or sub-populations of some species may remain in fresh water (*e.g.,* the freshwater form of sockeye salmon known as kokanee) or stay in coastal waters (many chinook and coho populations) but most engage in extensive migrations while at sea. In the Pacific, salmon usually return to their home rivers and natal breeding grounds to spawn and then die, except for steelhead salmon (*O. mykiss*) which may spawn repeatedly (Augerot *et al.* 2005). Although there are only 6 species of wild Pacific salmon in British Columbia (BC), high levels of habitat diversity and variable environmental conditions have combined with a strong tendency for salmon to "home" to their rivers of origin, promoting the rapid, postglacial, evolution of many thousands of salmon populations specifically adapted to local conditions (Riddell 1993). All six species of North American salmon are currently common in freshwater and marine ecosystems of the Pacific North Coast Integrated Management Area (PNCIMA) bounded by British Columbia's North and Central Coast (Figure I.1).

Although salmon undoubtedly occupied North America in the absence of human populations for millennia, human migration and settlement of North America, including PNCIMA, around the end of the last glacial retreat (12,000 yrs B.P.) initiated economic, cultural and ecological interactions between humans and salmon that have been maintained for thousands of years. Wild salmon serve as a vital source of food for First Nations people (Stewart 1977) and have played a central and now constitutionally protected role (Fisheries and Oceans Canada 2005; 2006) in the development of their rich culture and spirituality (Drucker 1963). Pacific salmon have also continued to play important roles in the historical, economic, and cultural development of recent generations of all Canadians living in British Columbia by providing jobs, income, and enjoyment for individuals, businesses, and communities (Fisheries and Oceans Canada 2005). In addition, thousands of populations of salmon continue to play key roles in natural ecosystems, nourishing a complex web of interconnected species distributed from the furthest reaches of the North Pacific Ocean to the headwaters of mountain streams throughout countries bordering the North Pacific Rim (Cedarholm *et al.* 2000; Stockner 2003; Naiman and Latterell 2005).

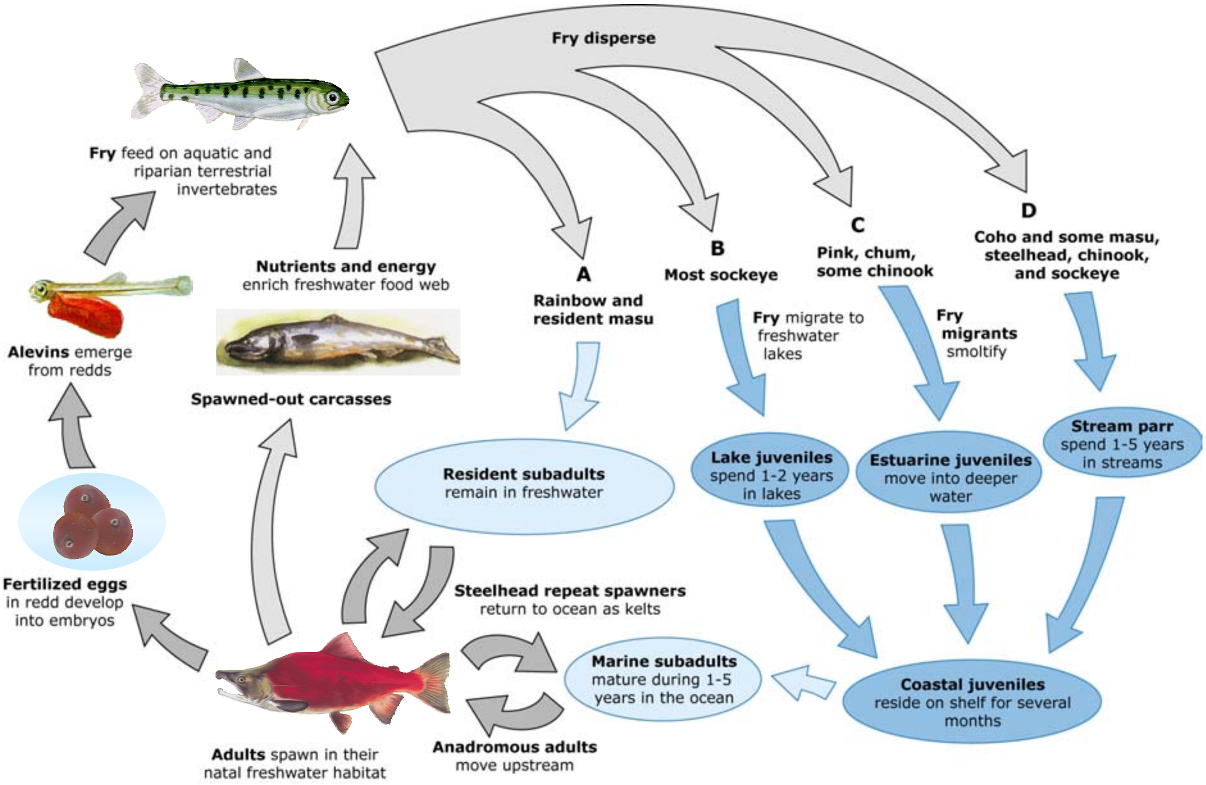


Figure I.0 General overview of Pacific salmon (Genus *Oncorhynchus*) life history patterns (adapted from Augerot *et al*. 2005).

1.2 Status and Trends of Salmon in PNCIMA

PNCIMA is an important migration corridor, marine rearing, and staging area for salmon migrating seaward as juveniles and then returning as adults to their coastal watersheds of origin. PNCIMA is occupied for a variable period of time not only by the majority of salmon stocks originating from British Columbia but also by many populations originating from the states of Washington, Oregon, and even California. The variable nature of their spatial and temporal associations within PNCIMA suggests that salmon may be considered in three classes including (1) resident in and originating from PNCIMA, (2) resident in but originating from outside PNCIMA, or (3) transients passing quickly through PNCIMA. Although PNCIMA is undoubtedly important to all three

Notes:

Source Information:

- BC Altimetry provided by NOAA
- Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
- Communities provided by NRCAN
- Lakes / Rivers provided by BC MOE

Projection: BC Albers, NAD 83
Production Date: June 18, 2007
Produced By: OHEB GIS Unit, DFO

Figure I.1 PNCIMA region showing locations and features of BC waters.

groups, the focus of information presented here on status and trends is largely restricted to those populations in class (1).

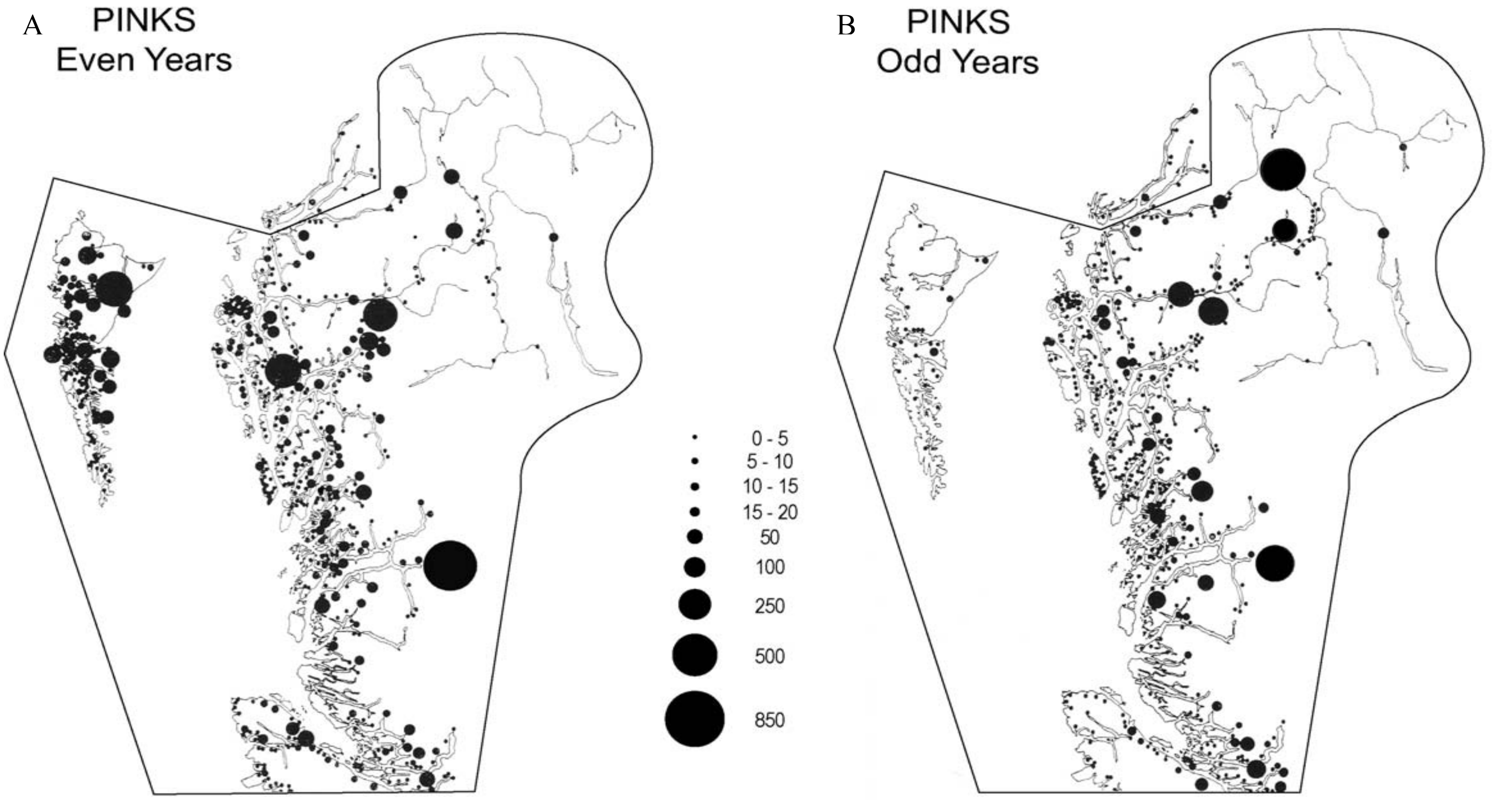
1.2.1 Status

Aro and Shepard (1967) compiled the first extensive synthesis of the status of populations of Pacific salmon spawning in Canada, including PNCIMA. They ranked the main spawning streams for each species in order of their average abundance during the years 1951-1962 and summarized a wide range of information for all "major" populations. Major populations were defined as those achieving escapements on two or more occasions above a set value for each species (*i.e.*, >5000 sockeye, >20,000 pinks, >10,000 chums, >2000 coho, and >500 chinook salmon) within the subject interval. Results suggested PNCIMA hosts approximately 383 major populations of 5 species of Pacific salmon including: 131 pink (58 odd-year, 64 even-year), 94 coho, 67 chum, 55 sockeye, and 36 chinook populations.

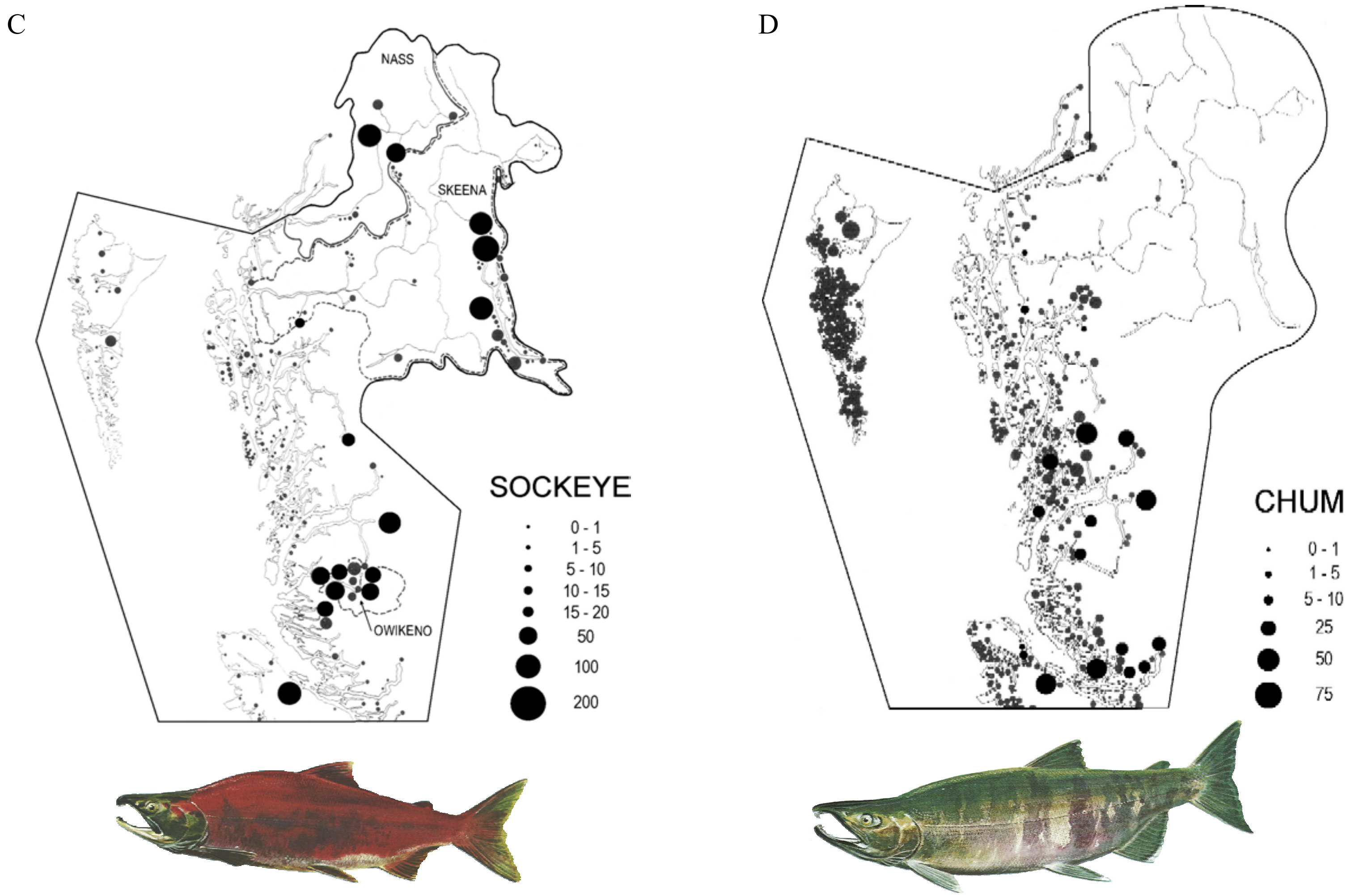
Pinks are the numerically dominant species of salmon in PNCIMA (mean total escapement >5 million adults). Pink salmon populations are distributed broadly throughout PNCIMA (Figure I.2a, 2b) but the majority of pink salmon production is associated with a few large populations (>250,000 spawners) returning to major river systems such as the Bella Coola-Atnarko (S-PNCIMA), the Kitimat (N-PNCIMA), the Yakoun (Queen Charlotte portion of PNCIMA) and the Skeena (NE-PNCIMA). Odd and even-year lines of pink salmon are well represented in rivers throughout PNCIMA except for Queen Charlotte Islands populations where even-year pinks (Figure I.2a) exhibit higher abundance and a broader distribution than odd-year pinks (Figure I.2b). In aggregate, chum is the second most abundant species of salmon in PNCIMA with local populations commonly exceeding 25,000 adults (Figure I.2d). The distribution of chum salmon populations is similar to that of even-year pink salmon including an especially high utilization of rivers on the Queen Charlotte Islands (QCI). On the mainland, the largest populations of chum are clustered in and around inlets tributary to Johnstone Strait and in areas immediately north of Dean Channel. Sockeye salmon populations are third in aggregate abundance, broadly distributed throughout coastal and interior watersheds of PNCIMA. However, populations originating from a few large lakes in the Nass (Meziadin and Bowser lakes), Skeena (Babine Lake), Nimpkish (Nimpkish and Woss lakes) and Rivers Inlet (Owikeno and Long lakes) areas of PNCIMA account for greater than 90% of average annual abundance (Figure I.2c) on the order of 1-3 million spawners. By contrast, scores of small populations containing fewer than 5,000 spawning adults account for less than 10% of the total escapement of sockeye to PNCIMA.

Among the 5 species of salmon considered by Aro and Shepard (1967), coho exhibited the widest and most equitable numeric distribution occupying not only major rivers but also small coastal streams and penetrating far into interior watersheds of PNCIMA (Figure I.2e). Most populations of spawning coho are small (<5000 spawners) with fewer than ten populations routinely containing more than 25,000 spawners (*e.g.,* Bella Coola R.). Chinook salmon were represented by the fewest populations and the lowest aggregate numbers (area wide escapement of <150,000 fish) among the 5 salmon species (excluding steelhead salmon). They exhibit highly disjunct distributions within PNCIMA (Figure I.2f) where they spawn in mainstem locations of a few large rivers often associated with the outlets of large lakes.

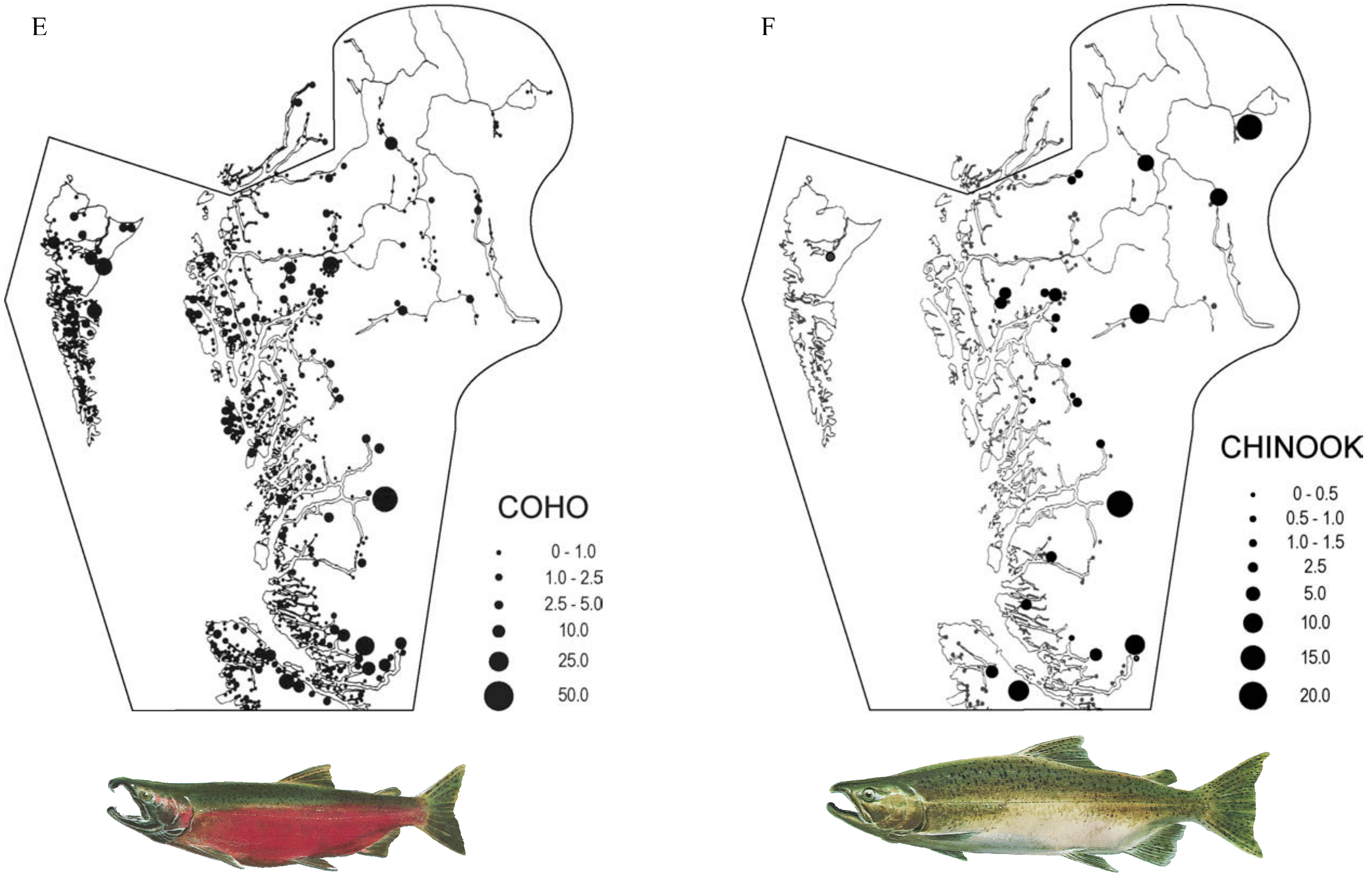
Aro and Shepard (1967) identified fewer than 400 “major” populations of 5 species of Pacific salmon in PNCIMA but clearly many of the smaller populations that contribute to the impressive biodiversity of salmon in the area were excluded from their list. A more recent review of the status of both “major” and “minor” populations of anadromous salmon and trout in British Columbia and the Yukon (Slaney *et al.* 1996) identified the existence of more than 9,000 site-specific, spawning populations among 6 species of Pacific salmon originating within Canadian waters. Hundreds of watersheds both large (*e.g.,* Nass, Skeena, etc.) and small (*e.g.,* QCI area) within PNCIMA provide critical spawning habitat for more than 5,000 spawning aggregations or approximately 58% of all anadromous salmon populations originating from Canada’s west coast (Table I.1).



Figures I.2a and I.2b Distribution and average abundance (1951-1962) of "major" spawning aggregations of even-year pink (a), odd-year pink (b), occupying freshwater streams, rivers, and lakes in PNCIMA (adapted from Aro and Shepard 1967).



Figures I.2c and I.2d Distribution and average abundance (1951-1962) of "major" spawning aggregations of sockeye (c), chum (d), occupying freshwater streams, rivers, and lakes in PNCIMA (adapted from Aro and Shepard 1967).



Figures I.2e and I.2f Distribution and average abundance (1951-1962) of “major” spawning aggregations of coho (e) and chinook salmon (f) occupying freshwater streams, rivers, and lakes in PNCIMA (adapted from Aro and Shepard 1967).

Table I.0 Numbers and status of resident salmon populations by species and area in PNCIMA (adapted from Table 2 of Slaney *et al.* 1996).

DFO Statistical Areas	**Extinct**	**High Risk**	**Medium Risk**	**Special Concern**	**Low Risk**	**Unknown**	**Total**	**% of all Stocks**
Nass (3B)	0	27	0	16	233	275	551	5.7
QCI (1, 2W, 2E)	0	84	6	2	557	419	1,068	11.0
Skeena (4)	2	44	1	38	432	435	952	9.8
North Coast (5)	0	41	5	0	267	271	584	6.0
Central Coast (6,7,8)	1	153	11	15	827	489	1,496	15.0
Rivers-Smith (9-11)	0	9	0	9	133	85	236	2.4
NWVI	0	43	4	9	289	336	681	7.1
PNCIMA Totals	3	401	28	89	2,738	2,310	5,568	57.6
(% of BC)	**2**	**64**	**36**	**39**	**62**	**55**	**58**	**58.0**
BC-total	142	624	78	230	4,417	4,172	9,663	100

The status of these stocks was assessed by employing a commonly used risk classification scheme (Nehlsen *et al.* 1991). Limits on quantitative information for 2,310 or 41% of PNCIMA salmon populations precluded any meaningful statement about their current status other than “status unknown”. However, for the 3,259 or 59% of salmon populations that were assessed, results suggested that: 84% were healthy (*i.e.,* virtually no short term risk of biological extinction), 12% were at high risk of loss, and only 3 populations (<0.1%) were confirmed as having gone extinct within recent history (Table I.1, see Slaney *et al.* 1996 for details of risk criteria).

Riddell (2004) adopted a different classification scheme in a Pacific Fisheries Resource Conservation Council (PFRCC) review of status and trends exhibited by salmon populations in PNCIMA, which may be considered for comparative purposes. Riddell concluded that no fewer than 2,983 populations of Pacific salmon originate from watersheds of PNCIMA. Ranked in order, these included 1,120 pink, 882 coho, 610 chum, 236 sockeye and 135 chinook salmon populations. Although the rank order of abundance of populations by species was similar among all three studies considered here, the Slaney *et al.* study identified the maximum number of salmon populations in the PNCIMA area (5,568 by Slaney *et al.* versus 2,983 by Riddell versus 383 by Aro and Shepard). Further, at least one recent study has suggested an even larger number of salmon populations may reside in PNCIMA, once small streams that are seldom surveyed are accounted for (Harvey and MacDuffee 2002). Differences between studies are largely attributable to variable screening criteria and boundaries used to identify populations falling within the geographic area of interest (*e.g.,* only Slaney *et al.* considered steelhead salmon and Riddell did not include populations from Northwest Vancouver Island).

Although screening criteria and procedures differed between the studies by various authors, general conclusions regarding PNCIMA salmon population status are similar.

Thus, Riddell's detailed consideration (Table 2.2 of Riddell 2004) of 117 sockeye stocks in PNCIMA suggested that available information was insufficient to support meaningful statements on the status of 44%, while 41% of all PNCIMA salmon populations that Slaney *et al.* considered could not be assigned a known status due to information limitations. Results from both studies suggest that, overall, salmon populations within PNCIMA currently exhibit lower levels of recent extinctions and/or proportionately fewer stocks at high risk than for salmon populations originating from areas south of PNCIMA (Nehlsen *et al.* 1991; Slaney *et al.* 1996). All studies agree that quantitative information on the status of relatively large and productive salmon populations that provide most of the biomass for commercial harvest for a given species is far superior to that available for the majority of small streams. The latter may often contain less productive populations but could account for most of the genetic biodiversity contained among populations. The widespread distribution of populations regarded as exhibiting high risk (Figure I.3) and the inability to currently classify the status of hundreds of small populations of all species in PNCIMA remains an issue of concern (Thomson and MacDuffee 2002; PFRCC 2005).

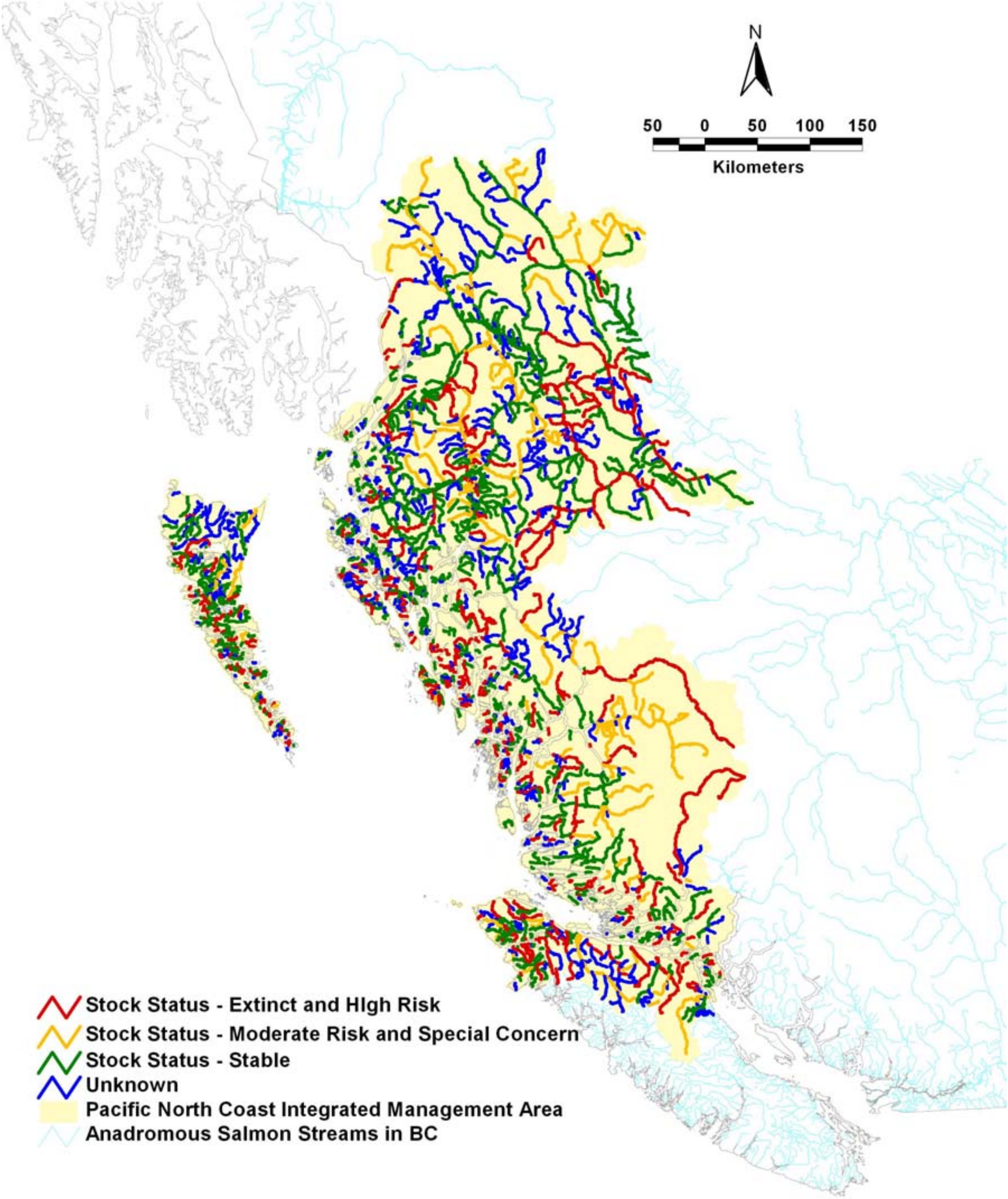


Figure I.3 Distribution of salmon stocks by risk category within PNCIMA as of 1993; red = high risk of extinction, amber = moderate risk or special concern, green = healthy, and blue = unknown status (adapted from Slaney *et al.* 1996).

1.2.2 Trends

Pacific salmon exhibit large fluctuations in abundance in both space and time, at levels ranging from local populations to entire species aggregates, summed within major geographic areas such as PNCIMA. Except for small areas in the Queen Charlotte Islands and possibly the northwest tip of Vancouver Island, most of PNCIMA was extensively glaciated and therefore largely devoid of salmon populations as recently as 12,000 years B.P. (McPhail and Lindsey 1986). Inferences about salmon abundance during the latter period are based on archaeological or paleoecological observations that provide insights into prehistoric change, along with stock assessment observations (*e.g.,* annual records of catch and spawning numbers) during the historic interval from the late 1800s to present.

Archeological evidence from studies of middens throughout the BC coast, including PNCIMA, indicates the presence of highly abundant salmon populations throughout the several thousand year interval of human occupation. However, archaeological observations are not sufficiently rich to use as a basis for inferences regarding numeric trends in prehistoric salmon abundance. Potentially more revealing, paleoecological investigations are underway in several PNCIMA locations (M. Pellat, Parks Canada, pers. comm., 2006) but, as yet, remain unpublished. However, published results from similar studies are relevant to inferences about potential long-term trends for salmon in PNCIMA as they confirm the occurrence of large natural variations in Pacific salmon abundance prior to the advent of industrial fishing and widespread landscape alterations associated with European settlement of the west coast. Thus, a >2000 year reconstruction of sockeye salmon abundance from analyses of lake sediment cores in Alaska (Finney *et al.* 2000; Gregory-Eaves *et al.* 2003) indicated large shifts in salmon abundance, far exceeding variations recorded there during the past 300 years. Taken in concert with other evidence, suggesting strong coherence of changes in regional fish populations (Francis *et al.* 1998; Beamish *et al.* 1999), paleoclimate results support the view that changes to ocean regimes and climate related factors alone may greatly influence salmon production patterns and abundance over centuries of time in geographic areas as large as PNCIMA.

During the recent historic period (late 1950s to present) detailed observations of spatial and temporal trends of salmon are available as records of salmon catch and spawner abundance (*i.e.,* escapement) within PNCIMA (Wong 1983; Serbic 1991; Department of Fisheries and Oceans, unpublished data). Examination of these records for salmon that utilize marine areas and that also originate from watersheds within PNCIMA suggests the following trends in total abundance among species and then within species. On average, 25-30 million adult salmon return each year to watersheds of PNCIMA. However, annual fluctuations in returns are large, ranging from 12 to 48 million adults, and the clear dominance of even-year pink numbers on total return patterns is evident throughout the time series (Figure I.4). At a gross level, catch and escapement observations reflect similar trends, where alternating periods of relatively low and then high production of salmon are evident in both catch and escapement records during the 1950s versus 1960s and then during the 1970s versus 1980s respectively. Total returns of salmon to

PNCIMA have declined to well below the all-year average during the most recent decade (1997-2006). Because of their numeric dominance in PNCIMA, pink, chum and sockeye salmon aggregates exhibit few departures from the all-species pattern just described (Figures I.4b, I.4c, and I.4d). Notable exceptions to this are the spectacular collapse of two major populations of sockeye salmon at Rivers Inlet (Owikeno Lake) and Smith Inlet (Long Lake) that, in aggregate, produced average annual returns in excess of 1.3 million salmon for the entire period from 1950-1993 but then declined sharply thereafter to minimum single year returns reported at less than 10,000 adults and multiyear returns averaging less than 100,000 adults (Riddell 2004). McKinnell *et al.* (2001) provided evidence that the collapse of these neighboring sockeye stocks within PNCIMA was attributable to as yet unknown events that influenced survival during the marine portion of their life history.

Chinook salmon production in PNCIMA has exhibited relatively little variation (Figure I.4e) averaging roughly: 300,000 during the 1950s, increasing to roughly 400,000-500,000 during the 1965-1995 interval and then dropping below average returns of 300,000 adults after 1998. Coho salmon production trends contrast with that of other species in that total returns appear to be on the order of 1.9 million during the 1950-1970 interval, 1.5 million during the 1970-1990 interval and then averaging less than 900,000 adult returns from 1991 to present. In retrospect, gradual declines of coho production in PNCIMA were underway by the late 1960s, becoming pronounced by the mid-1990s, followed by modest rebuilding of the stock-aggregate after 1997 (Figure I.4f).

General factors controlling trends in salmon production in PNCIMA include the influence of exploitation by distant and domestic fisheries; climate-induced changes in freshwater and marine productivity; targeted stock and enhancement activities (Riddell 2004; Fisheries and Oceans Canada 2006); and the influence of forest harvest, agricultural development, mining and water regulation activities on salmon habitat (McAllister *et al.* 1997; Harvey and MacDuffee 2002). Only limited generalizations are possible about the specific influence of any one or combinations of these factors on trends in salmon abundance throughout PNCIMA. Long term trends for coho salmon declines appear to have been related to combinations of downturns in stock productivity combined with exploitation rates that were non-sustainable during the 1970s and 1980s (Holtby *et al.* 2002). Similarly, significant reductions in chinook catches, mandated by the Pacific Salmon Treaty beginning in 1985, were accompanied by increases in escapement and subsequent total production of chinook salmon in PNCIMA during the late 1980s to mid-1990s (Riddell 2004) but have declined, somewhat inexplicably, since the late 1990s. Industrial logging and agricultural development clearly have considerable potential to influence many local area salmon populations but no studies completed to date have offered definitive evidence that the extent of these activities in watersheds or coastal areas of PNCIMA are controlling salmon production (McAllister *et al.* 1997).

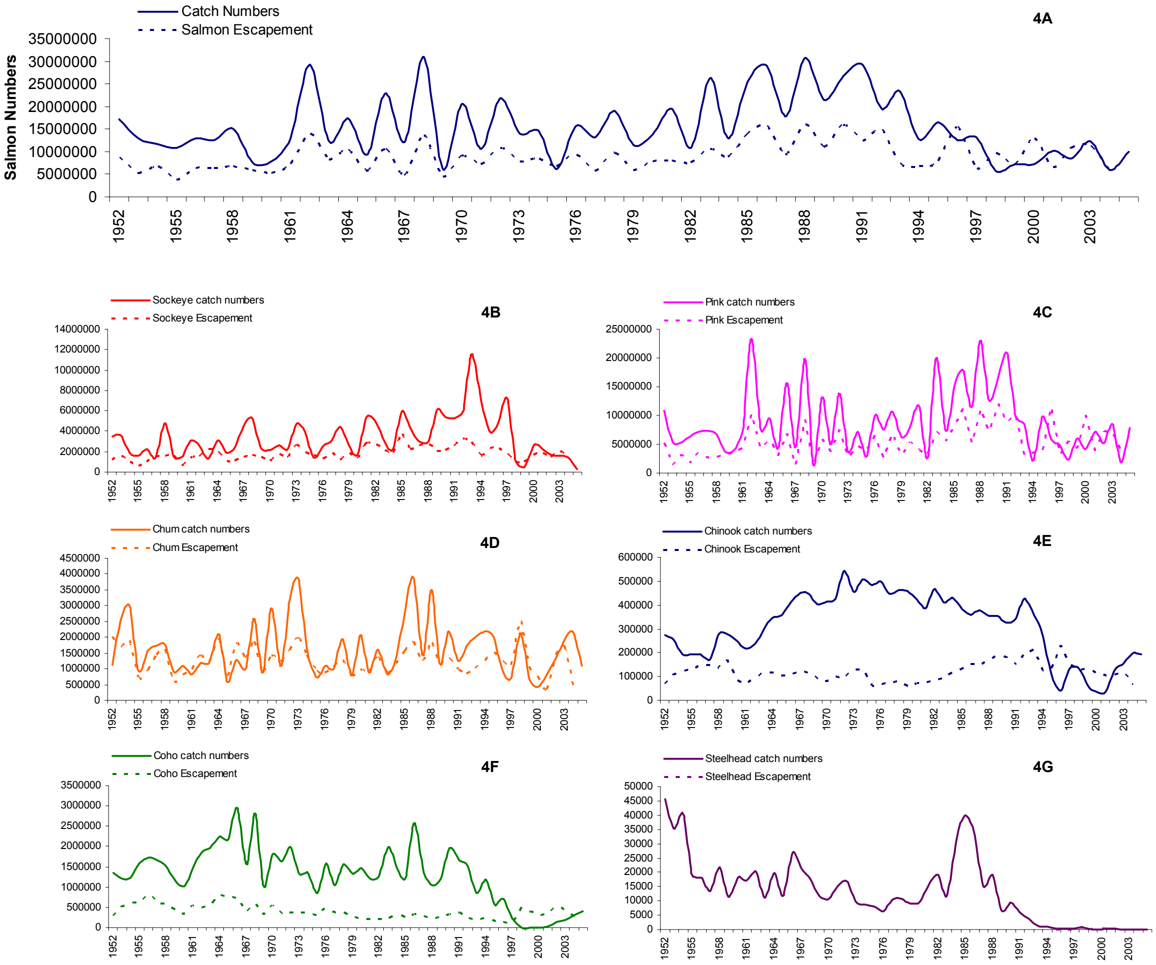


Figure I.4 Total annual returns (catch plus escapement) of (a) all salmon to PNCIMA between 1950-2004 including: (b) sockeye salmon, (c) pink salmon, (d) chum salmon, (e) chinook salmon, (f) coho salmon, and (g) steelhead (catch only). Data provided by DFO Salmon Assessment Section staff, Pacific Biological Station, Nanaimo, BC.

Mueter *et al.* (2002b) investigated spatial correlations between marine environmental variables and survival rate indices of salmon along the west coast of North America, including PNCIMA. Their analyses suggested that associations between salmon survival and near coastal environmental variables (upwelling index, sea surface temperature [SST], and sea surface salinity [SSS]) were strongest at local spatial scales (distances of <500-800 km) for adjacent stocks and exhibited little or no co-variation at spatial scales larger than 1000 km. Among the three variables examined (upwelling, SST, and SSS), correlation scales for SST in summer most closely matched the observed correlation scales for survival rates of salmon. Moreover, regional averages of SST appeared to be better predictors of survival rates than large-scale measures of SST variability such as the Pacific Decadal Oscillation (PDO; Mueter *et al.* 2002a). This suggests that regional-scale variations in SST along the coast are related to the processes causing the observed co-variation in survival rates among neighboring salmon stocks such as Smith and Rivers inlets sockeye. Consequently, neighboring PNCIMA stocks may be expected to exhibit stronger similarities in survival and production variations than stocks separated by larger distances. Similar analyses, involving comparisons among stocks of sockeye, pink, and chum salmon suggested that geographical overlap of different salmon species during freshwater and early marine life stages are more important in determining shared environmental effects on survival rates (*and ultimately on stock productivity*) than are inherent differences in life history strategies between species (see Pyper *et al.* 2005 for details).

2.0 HISTORY OF EXPLOITATION AND MANAGEMENT

2.1 Salmon Exploitation – Aboriginal Fisheries

The abundant resources of the temperate Northwest Coast supported one of the world's densest non-agricultural, human populations for thousands of years prior to European contact. West coast peoples engaged in specialized hunting and fishing, crafts and curing; created social units larger than villages, elaborate ceremonies, and one of the world's great art styles (Harris 2001). Following Suttles (1990), indigenous cultural groups in PNCIMA include the Haida (Queen Charlotte Islands), Niska (Nass Valley), Gitskan and Coastal Tsimshian (Skeena River and coastal areas), Haisla (Kitimat, Gardner Canal and Kitlope area), Bella Coola, Heiltsuk and Southern Kwakiutl (northern Vancouver Island and mainland inlets).

The exploitation of fisheries, including salmon, has been described as the foundation of the Native economy (Drucker 1963), where orientation towards the sea and rivers regulated settlement patterns and was reflected in social organization, culture and religion (see pp. 18-19 of Augerot *et al.* 2005). The principal unit of social organization on the Northwest Coast was the local kinship group who lived together, worked together, and who jointly considered themselves exclusive owners of the tracts and sites from which food, including salmon, was obtained. Argue and Shepard (2005) note that the precise extent of Aboriginal utilization of salmon prior to first contact with Europeans (circa 1770s) is a matter for speculation. Pre-contact estimates of indigenous populations of people on the order of a hundred thousand or more (Duff 1965), combined with annual per capita consumption rate estimates of several hundreds of salmon, led Argue *et al.* (1990) to suggest annual utilization levels by Aboriginal populations of 18,000 tonnes (about 5.2 million fish), a level rivaling harvest by the early commercial fishery in the late 1800s. Thus Aboriginal harvest of Pacific salmon was substantial during the period prior to European settlement and salmon may be regarded as a "cultural keystone species" (Garibaldi and Turner 2004) that played a fundamental role in the diet, in addition to serving as cultural icons in the language, ceremonies, and narratives of Native peoples.

Population estimates for all Native groups in PNCIMA combined, and prior to first contact with Europeans, have been estimated at roughly 60,000 people (p. 136, Table 1 of Boyd in Suttles 1990). Native peoples throughout PNCIMA employed stone tidal-ponds in salt water and traps and weirs in rivers, as well as harpoons, leisters, dip-nets and trawl-nets to fish for salmon (see chapters on specific cultural groups in Suttles 1990). Although all species were eaten fresh, chum salmon were smoke-dried in great quantities for winter food supplies, because the fat content was lower and the product less likely to go rancid. The failure of a salmon run could presage a winter of privation and many myths refer to actual starvation (Cove 1978). Accordingly, the sites for harvest of salmon were prized and closely surrounded with a variety of "regulations" concerning access, entitlement, and moderation of salmon harvest both within and external to the kinship group (see references and descriptions in Harris 2001). Evidence presented by some authors (*e.g.,* see Cannon 1992) suggests that then, as now, relative variations in scarcity and abundance of salmon, along with control over access, promoted both trade and conflict between and among local fishing groups. However, both the details and the impact of Aboriginal management practices on salmon and their use are subjects for considerable speculation where current knowledge remains fragmentary. What may be said with certainty is that prior to 1880 the Pacific coast salmon fishery was largely a Native fishery controlled by a complex set of customs and regulations originating from centuries of Aboriginal culture.

2.2 Salmon Exploitation – Contemporary Fisheries

The development of the modern salmon fishery and associated management systems followed a similar pattern in all areas of the coast (Lyons 1969; Hyatt and Steer 1987; Argue and Shepard 2005). Use of fresh, salted, or dried salmon for subsistence purposes by fur traders and settlers from the early to mid 1800s was small (probably <200 tonnes) compared to use by Aboriginal peoples (Argue and Shepard 2005). However, by the late 1800s successful development of techniques for canning salmon, combined with developing export markets for the product, stimulated the creation of a capture and processing industry involving 20 canneries in 1880 increasing to more than 80 scattered throughout the BC coast by 1917 (Hyatt and Steer 1987). No fewer than half of these canneries were located in PNCIMA, including 6 on the Nass R., 14 on the Skeena R., 9 at

Rivers and Smith inlets, plus scores of others sited in inlets and at the mouths of rivers (Lyons 1969), wherever sufficient supplies of salmon could be captured by nearshore gill-nets or drag-seines (*e.g.*, see Appendix 2 of Campbell 2004 for specific locations of canneries in PNCIMA in 1932). Sockeye, coho, and chinook salmon comprised most of the rapidly increasing catch prior to 1900 when total harvest remained below 10,000 tonnes (Figure I.5). However, by 1910 all five species of salmon and steelhead were included in steeply increasing catches facilitated by the introduction of rapid technological change in all sections of the coastal industry (*e.g.,* see Hyatt and Steer 1987 for the typical progression in a salmon fishery). Salmon catch peaked above 40,000 tonnes in PNCIMA around 1928, only 4 years after a prohibition against use of motorized fishing vessels was rescinded (Figure I.5). Total catch of salmon fluctuated between 20,000 and 35,000 tonnes during 1930-1980 and then peaked above 40,000 tonnes again in the mid-1980s due to variations in the availability of both wild and enhanced salmon. However, while the catch circa 1928 was processed in no fewer than 46 facilities scattered throughout PNCIMA, technological change (*e.g.,* introduction of packers equipped with freezers or cold-brine circulating tanks) facilitated consolidation of transport and physical plants for salmon processing. By 1975, this had resulted in the closure of virtually all of the fish processing facilities located in mainland areas of PNCIMA from immediately south of the Skeena River in the north to Port Hardy on Vancouver Island (see Map 42 in Farley 1979).

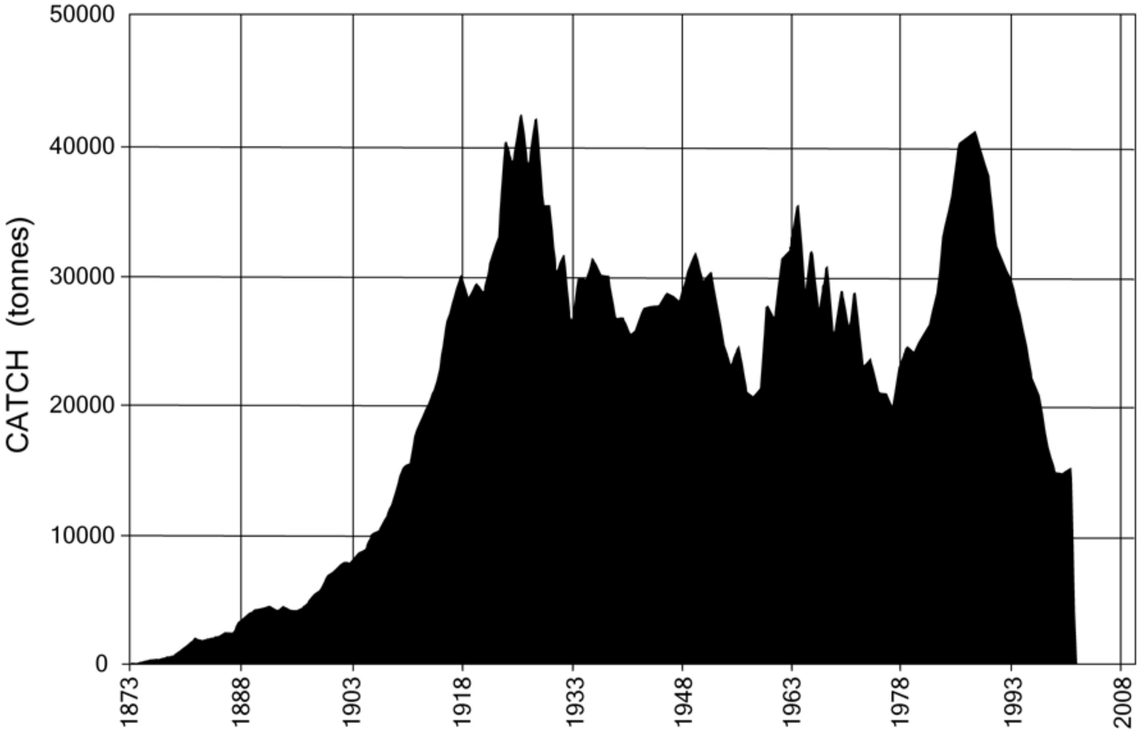


Figure I.5 Annual British Columbia catch (tonnes) of all salmon species, 1873-2001, within PNCIMA (DFO Statistical Areas north of Cape Caution). Catches summed across all species and presented as a 5-year moving average (from Argue and Shepard 2005).

Comparisons of the spatial distribution and species composition of salmon catches within PNCIMA in the 1950s (Figure I.6a), the 1970s (Farley 1979) and then again in the 1990s (Figure I.6b) suggest some obvious trends for coastal fisheries. First, catches of salmon generally reflect the relative abundance of species within or among areas such that pink and/or sockeye account for the largest proportions of catch, chum salmon are next, followed by coho, then chinook, and finally steelhead salmon. Next, salmon catches were more equitably distributed among areas of the coast in the 1950s than in more recent intervals. This reflects relatively recent decreases in demand for pink salmon that dominated catches in most areas in the 1950s and the greater consolidation of fishery effort focused on high-value sockeye salmon (compare Figure I.6a versus I.6b) at the mouths of the Nass R. (Area 3), Skeena R.(Area 4), and Johnstone Strait (Areas 11-12). Finally, coho salmon comprised a larger portion of the catch both from directed and incidental harvest during the 1950s than during the 1990s when coho declined and fisheries managers responded by restricting both directed and incidental catch in troll and net fisheries respectively (Holtby *et al.* 2002). Steep declines in total catch during the 1990s are attributable to a complex set of factors including: changes to harvest management to conserve and restore depressed populations affected by overfishing and environmental degradation in some areas (Harvey and MacDuffee 2002; Riddell 2004); climate-induced declines in the productivity of marine and/or freshwater ecosystems that support salmon populations associated with PNCIMA (*e.g.*, sockeye at Rivers and Smith inlets; McKinnell *et al.* 2001); and changes in the economics of the wild fishery driven by increasing costs (*e.g.,* for fuel and labour), increasing competition for market share (*e.g.,* from farmed salmon and highly productive Alaskan fisheries) and decreasing revenues.

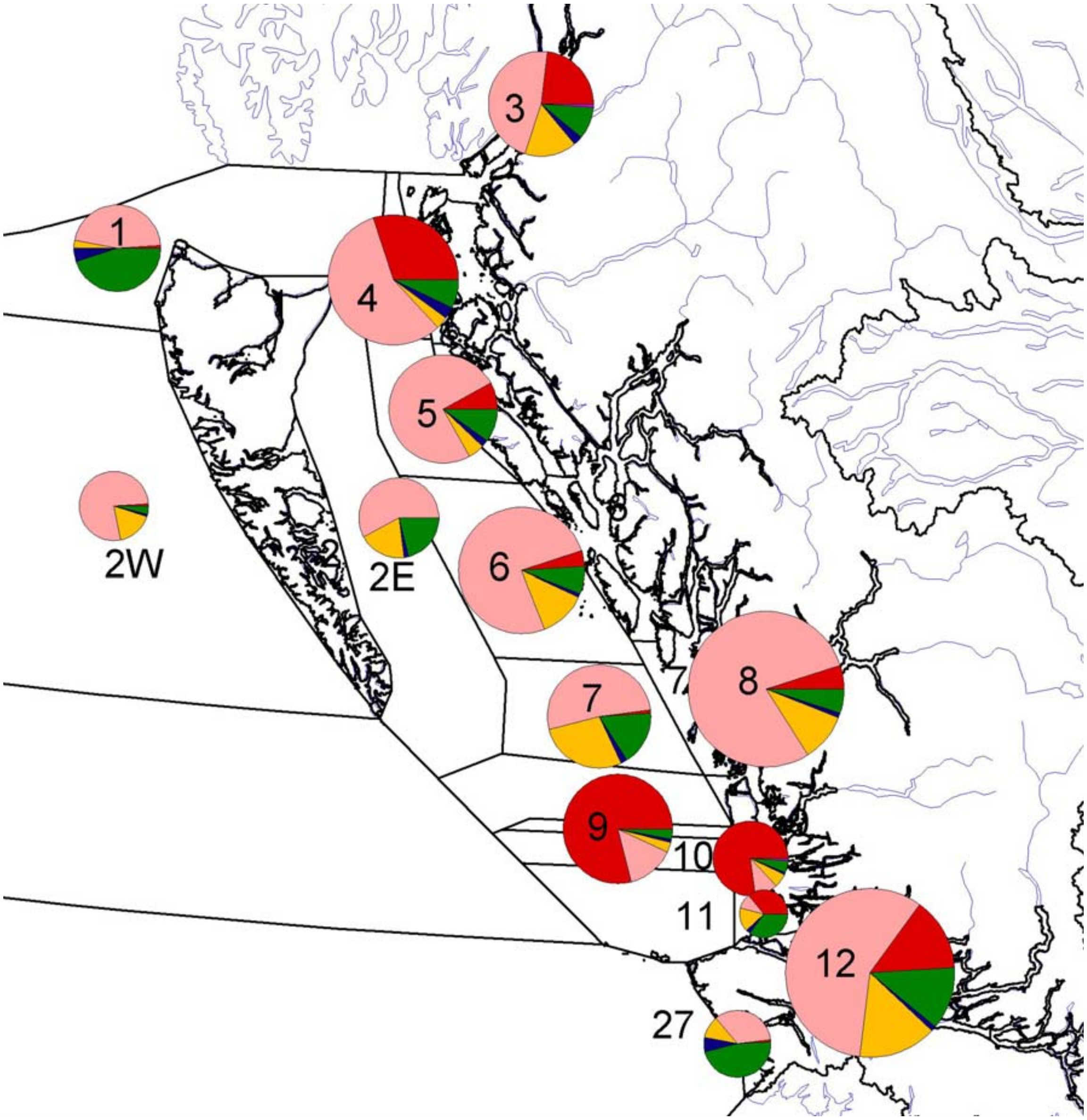


Figure I.6a Distribution of average catch of salmon within PNCIMA during 1951-1963 inclusive. Symbol sizes are scaled within time period to largest total catch by number in a statistical area. Species are identified by colours where: pink = pink salmon, red = sockeye salmon, gold = chum salmon, green = coho salmon, and blue = chinook salmon.

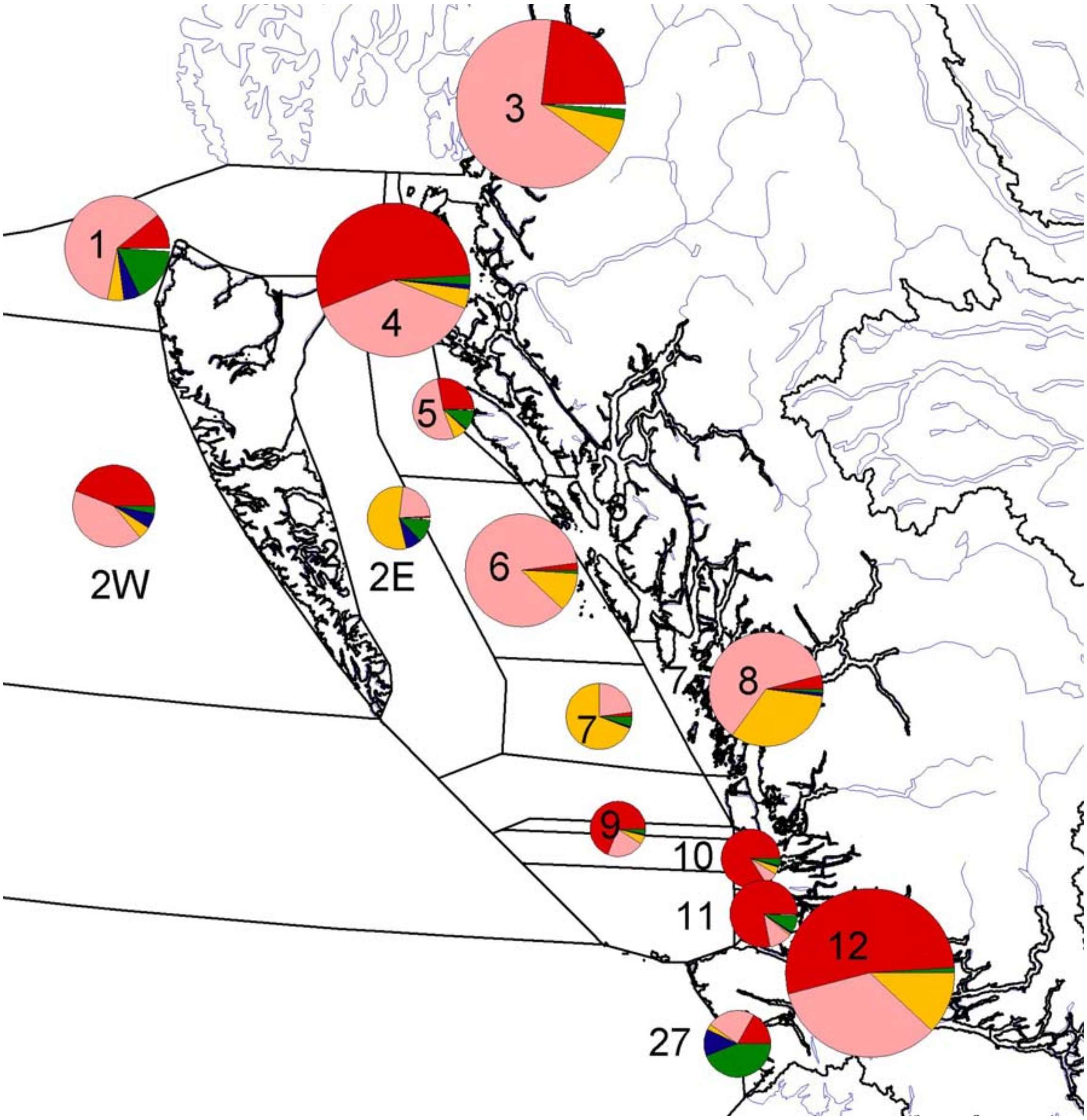


Figure I.6b Distribution of average catch of salmon within PNCIMA during 1992-2003 inclusive. Symbol sizes are scaled within time period to largest total catch by number in a statistical area. Species are identified by colours where: pink = pink salmon, red = sockeye salmon, gold = chum salmon, green = coho salmon, and blue = chinook salmon.

In addition to commercial fisheries, recreational fishing focused on chinook, coho, and steelhead salmon occurs in areas scattered throughout PNCIMA, but generally does not harvest a large proportion of the majority of salmon populations returning to watersheds there. However, very high-value recreational fisheries may focus significant effort on salmon stocks for which either exceptional biological traits (*e.g.,* large size) or exceptional surroundings (*e.g.,* pristine wilderness) generate high demand in some sub-areas of PNCIMA. Examples of these fisheries include coho and chinook fisheries operating out of lodges at Langara Island (QCI), at Hakai Pass and Dawson's Landing (Rivers Inlet and Central Coast), and Princess Royal Island. In addition, world renowned fisheries for steelhead salmon occur in many PNCIMA rivers including the Dean and Atnarko (central PNCIMA) along with many tributaries of the Skeena River system (northeast PNCIMA).

2.3 Salmon Management

Between the 1870s and 1880s, the industrial commercial fishery, based largely on the export of canned salmon, came to dominate the west coast fishery (Lyons 1969). Although the history of its development is beyond the scope of detailed treatment here, state control of both the Native and non-native fisheries was increasingly realized through implementation of provisions of the Fisheries Act of 1868 and subsequent provision of Fishery Regulations for the Province of British Columbia in 1894 (see Harris 2001 for an excellent account). Thus, by the early 1900s a previously scattered and small-scale salmon fishery had become a highly regulated industry. At the time of the 1920s peak catch of salmon, the licensed BC salmon fleet included about 4,600 gillnet, 2,600 troll, and 278 seine vessels from which the combined fishing power represented an increasing threat to the sustainability of the salmon resource. In 2003, following the Department of Fisheries and Oceans (DFO) interventions to achieve fleet and harvest effort reductions, there were 1,406 gillnet, 539 troll and 276 seine boat licenses on just over 2000 active salmon vessels. About 50% of these participate in various fisheries in PNCIMA. Throughout the last century, DFO and its predecessors have pursued the development of sustainable management of the salmon resource (Hyatt and Riddell 2000). Thus, harvest is regulated to ensure sufficient adults return to the spawning grounds to produce the next generation of fish. This is accomplished through a system of fishing licenses combined with enforcement of seasonal-time and statistical-area (see Figures I.6a and b) restrictions to control catch and effort by gear types (*e.g.,* recreational, troll, gillnet, seines) in specific areas (Figure I.7) or by sectors (*i.e.,* Native, recreational, and commercial) of the salmon fishery.

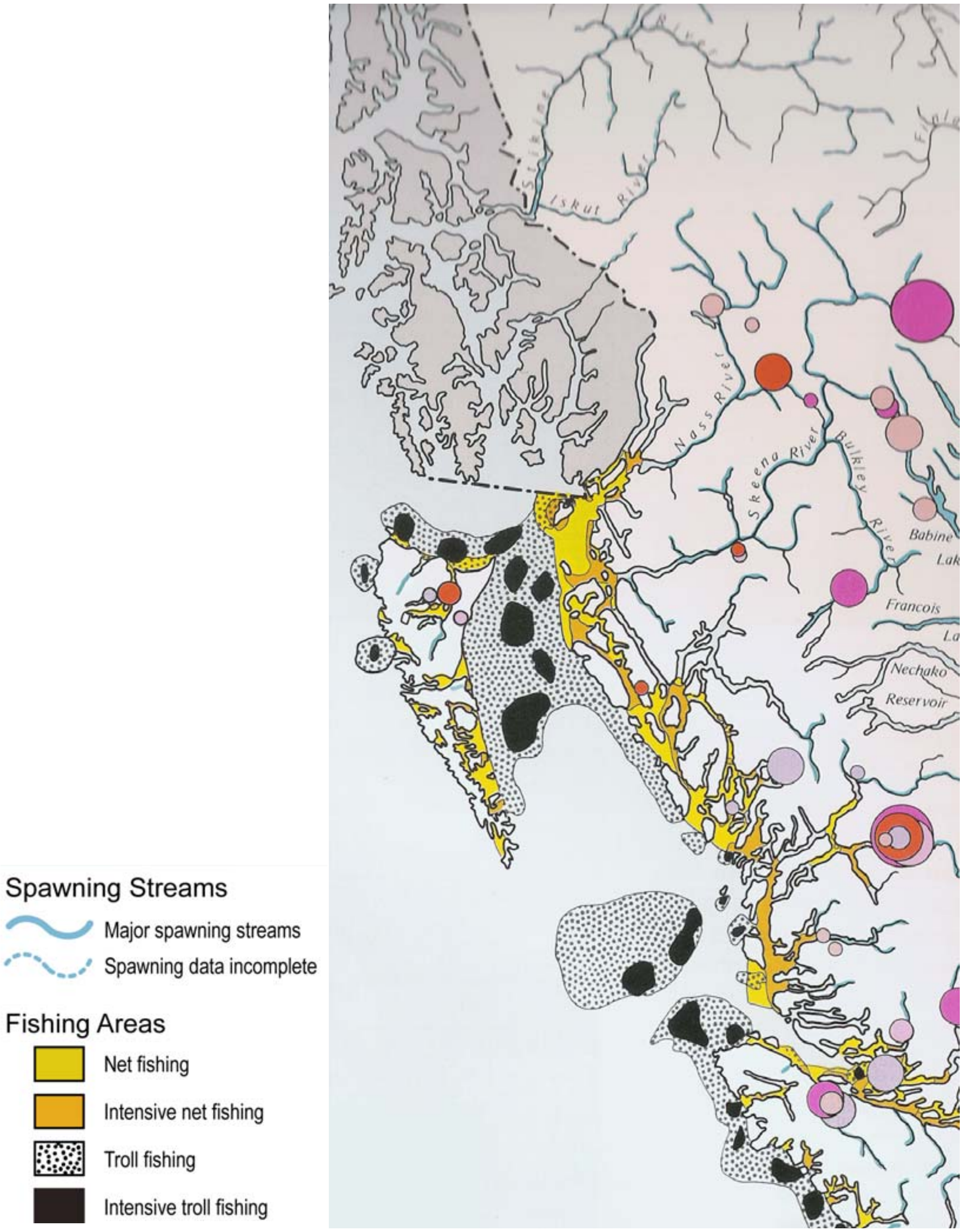


Figure I.7 Major and minor areas of operation for the British Columbia troll and net-fishing fleets. Alaskan net fisheries also exist near Noyes Island and Cape Fox (*i.e.,* just across the US-Canada border with Alaska) to intercept salmon bound for the Nass and Skeena rivers of PNCIMA (from Farley 1979).

The major components of contemporary management of major and minor salmon fisheries in PNCIMA (>50 separate fisheries in 2005 alone, Fisheries and Oceans Canada 2006) involve: (1) developing concurrent biological, economic, social, and legal objectives; (2) forecasting run size and formulating fishing plans; (3) consulting with user groups; (4) finalizing fishing plans; (5) executing fishing plans; and (6) evaluating management impact on the resource (*e.g.,* see Sprout and Kadowaki 1987). Details of the current policy context, management objectives, decision guidelines, and specific management measures by fishing area and subject species in PNCIMA are provided annually in an integrated fisheries management plan for northern BC salmon (Fisheries and Oceans Canada 2006). Briefly summarizing from that plan here, DFO policy for management of the fisheries is guided by a range of factors that include international and domestic initiatives that promote biodiversity, and a precautionary, ecosystem based approach to the management of marine resources. The latter entail implementation of international or domestic policy and operational initiatives outlined in: The Canada-US Pacific Salmon Treaty, Canada's Policy for the Conservation of Wild Salmon (WSP, see section 6.0 for more details), An Allocation Policy for Pacific Salmon, A Policy for Selective Fishing, A Framework for Improved Decision Making in the Pacific Salmon Fishery, and Catch Monitoring. These initiatives, among others, have been taken to ensure progress towards satisfying four key themes in the management of Pacific salmon fisheries (Fisheries and Oceans Canada 2006, p. 16, Section 2.4), which are: (1) sustaining strong salmon populations by setting clear conservation objectives for each fishery, based on the principles of the Wild Salmon Policy; (2) strengthening DFO programs that are critical to salmon conservation, such as habitat protection, enforcement, and the scientific assessment of stocks; (3) making progress over time in increasing First Nations access to economic fisheries; and (4) improving the economic performance of fisheries so that they reach their full potential, provide certainty to participants, and optimize harvest opportunities.

3.0 STOCK AND FISHERY ASSESSMENT PERFORMANCE INDICATORS

Given the great biodiversity of salmon populations found within PNCIMA, the complexities of their life histories and of the fisheries that harvest them, a wide range of stock and fishery performance indices are used to assess status and trends of Pacific salmon (McDonald 1981). Catch and escapement are principal among these, but a variety of additional information types (*e.g.,* biological traits such as size and age, migratory timing, preferred migration routes, etc.) are assembled to inform management decisions, dependent on the salmon species and the type of fishery (recreational, subsistence, commercial troll, or net). For example, sockeye, pink, and chum salmon are primarily intercepted by gillnet and seine fisheries at inshore locations (Figure I.7, net fishing) as the fish follow the coastlines of southeast Alaska and then sub-areas of PNCIMA during return migrations to their watersheds of origin. Information from pre-season forecasts of expected abundance, in-season assessments of catch and escapement to date in one or more fisheries, assessments of stock composition where returns consist of salmon stock mixtures (*e.g.,* large mixed stock fisheries for Skeena or Nass sockeye in Areas 3-5, Sprout and Kadowaki 1987, or passing stocks of Fraser River sockeye harvested in Area 12), plus knowledge of average return timing patterns, is used by fisheries personnel to adjust harvest activities to ensure enough spawners escape the fishery to sustain contributing stocks and the fishery in future years. Forecasts of adult returns are generally based on pre-fishery indices of abundance such as the abundance of seaward migrating juveniles or the number of adult spawners from which a given year's return is derived. Because fisheries for sockeye, pink, and chum salmon occur in a limited number of discrete locations, harvest monitoring and biological sampling efforts are focused in these locations to support annual abundance estimates of each stock. The reliability of these estimates depends greatly on whether the fishery involves a single stock (*i.e.,* highly reliable), simple mixtures of several major stocks (*i.e.,* medium to high reliability), or complex mixtures of a few major and many minor stocks (*i.e.,* reliable for major stocks but much less so for minor ones).

Chinook and coho salmon are caught not only near their watersheds of origin by restricted-area, gillnet and seine fisheries (often as bycatch) but also in hook-and-line fisheries (*e.g.,* commercial troll and recreational gear) dispersed throughout United States (US) and Canadian coastal waters. Consequently, hundreds of coho and chinook salmon populations may co-occur for varying intervals in a given harvest area such that the stock composition of catches is both complex and subject to rapid change. Moreover, reliable spawner enumeration of chinook and especially coho salmon is frequently problematic due to their use of either highly dispersed or inaccessible spawning sites (large, deep river channels by chinook, thousands of small headwater tributaries by coho) where assessment procedures are difficult to execute. Thus, sampling strategies and performance indicators to assess the status, track trends, and manage coho and chinook salmon are dependent on (1) development and maintenance of a limited number of "indicator" stocks for which high quality information is assumed to represent the status and performance of all stocks of a given species in each major area of the coast (Holtby *et al.* 2002 for coho; Riddell 2004 for chinook) and (2) maintenance and application of information from a coast-wide, coded-wire-tag (CWT), mark-and-recovery program operated jointly by Canada and the US.

The CWT program allows the systematic recovery of tags to assess the spatial distribution of catch and stocks, exploitation rates, and ultimately marine survival rates of marked juvenile chinook and coho salmon originating from index stocks that appear in various ocean commercial and recreational fisheries. Region-specific trends in marine survival, along with estimates of escapement for stock aggregates, are used for assessment and as a basis for forecasts of future abundance (*e.g.,* Holtby *et al.* 2002) to determine sustainable harvest levels for chinook and coho salmon. Coho index stocks in PNCIMA are located at Lachmach River, Toboggan Creek, and the Fort Babine Hatchery. Various chinook populations scattered throughout PNCIMA are used to follow trends in escapement (CTC 2004b). Kitsumkalum chinook, originating in a tributary to the Skeena River, serves as the only exploitation rate indicator (McNicol 1999) for North and Central Coast mixtures of Canadian stocks harvested by Alaskan and Canadian fisheries (CTC 2004a).

4.0 THE SALMON-HABITAT COMPLEX OF PNCIMA

Adaptive radiation of the Pacific salmon species complex following the most recent glacial retreat around 12,000 B.P. has resulted in thousands of locally distinctive populations that occupy freshwater and marine habitats throughout PNCIMA. To understand the full range of habitats occupied and the importance of its condition for maintenance of both salmon biodiversity and sustainable fisheries requires a brief consideration of key life history details that influence the distribution and abundance of the various salmon species and then a description of the current state of the salmon-habitat complex in PNCIMA.

4.1 Salmon Life Histories

Authoritative reviews of Pacific salmon life histories (Groot and Margolis 1991) provide key life history details related to species habitat requirements as follows.

4.1.1 Pink Salmon

Pink salmon (*O. gorbuscha*) are the smallest (1.5-2.5 kg) species of Pacific salmon and the least dependent on the freshwater environment. The center of pink salmon distribution in the eastern Pacific lies between south-central and southeastern Alaska. Thus, pink salmon in PNCIMA are located within the southern third of the species range in North America. Given their small body size, pink salmon are not especially adept at negotiating high velocity barriers or waterfalls that other Pacific salmon can surmount. Thus, most pink salmon populations migrate relatively short distances into rivers (typically less than 100 km) and in many short, coastal streams make significant use of inter-tidal areas where they spawn in large aggregations. Pink salmon spawning beds consist primarily of coarse gravel with a few large cobbles, a large mixture of sand, and a small amount of silt. Given their small size, pink salmon select spawning sites in relatively fast currents (as opposed to areas of sub-gravel upwelling) that facilitate gravel displacement during redd construction by females. Pink salmon have a fixed two-year life cycle such that they occur as even- or odd-year cohorts, which are reproductively isolated, even among those that use the same spawning streams year after year.

The peak of pink salmon returns to coastal rivers of PNCIMA occurs in July and August with spawning concentrated in late August and September. Pink salmon fry emerge from redds in March and April when they migrate immediately to sea. Pink salmon fry occupy near-shore waters of estuaries and coastal inlets for several weeks to months of time when feeding and growth depend on zooplankton and epibenthic organisms derived from estuarine and detritus-based food-webs. Following their estuarine and/or coastal inlet transition, pink salmon rapidly migrate northwest through PNCIMA waters to the Gulf of Alaska (GOA) before returning as adults to fresh water having spent more than a year at sea. Pink salmon exhibit less fidelity to their stream of birth than other species and so there are high rates of gene flow among local populations which, in aggregate, make up a few large regional meta-populations that are genetically similar.

4.1.2 Chum Salmon

Chum salmon (*O. keta*) are the second largest (3-6 kg) species of Pacific salmon. The distribution of chum salmon in North America is similar to that of pink salmon except that chums are found in appreciable numbers both further north and south than pink salmon. They are closely related to pink salmon (Allendorf and Utter 1994) and like the latter spend minimal time as juveniles in fresh water. They spawn in the lower reaches, side channels and tributaries of gravel-bed rivers, and spawning sites are often associated with upwelling groundwater along the margins of streams and in side-channels. In short coastal streams, chum may spawn in areas of tidal influence but rarely occupy the lower, inter-tidal areas commonly used by pink salmon. Given large body size, chum salmon are powerful swimmers and adept at long distance migrations. However, they are not great leapers and are generally found below the first barrier of any significance in a river.

Chum salmon return to coastal waters and rivers of PNCIMA in July through September with spawning concentrated in late September to early November. Early and late spawning runs of chum salmon are very common throughout their range, where early or summer-run adults utilize mainstem, spawning locations while fall-run fish use upwelling groundwater areas that maintain higher incubation temperatures through the winter. Chum salmon fry emerge from the gravel in March and April and migrate immediately to coastal estuaries where diets are frequently dominated by amphipods and benthic copepods. Chum salmon spend 2-4 summers at sea returning as 3-5 year-old adults to spawn in fresh water. Chum salmon exhibit considerable fidelity to their natal spawning areas and consequently exhibit higher levels of genetic differentiation and a larger number of distinctive population units within PNCIMA than pink salmon do.

4.1.3 Sockeye Salmon

Sockeye (*O. nerka*) are the fourth largest species of Pacific salmon in terms of average weight, which ranges between 1.5-3.5 kg. The latitudinal distribution of sockeye salmon is similar to that of pink salmon, so sockeye salmon in PNCIMA represent populations in the southern half of the species range in North America. Spawning and rearing habits of sockeye are both variable and complex. They routinely spawn in the mainstems or side-channels of gravel-bed rivers, in groundwater-fed springs, or on gravel beaches and outwash fans of lakes. Although sockeye populations are commonly associated with lakes used by juveniles for 1-3 years after fry emergence, there are also many small, relatively unproductive populations that spawn in rivers and streams that lack obvious lake rearing areas. Fry of these sockeye populations rear in side channels of rivers, in coastal estuaries or may migrate to sea soon after emergence. Sockeye production in PNCIMA is dominated by a few highly productive populations associated with large lakes located on the coast and far inland (*e.g.,* Babine Lake on the Skeena R.) but there are scores of small populations in the short river and lake complexes distributed throughout PNCIMA (Figure I.2c). Sockeye are strong swimmers and good jumpers, so they gain access to habitat above cascades and barriers that neither chum nor pink salmon negotiate.

Sockeye salmon returns to coastal waters and rivers of PNCIMA occur from June through August followed by spawning from mid-September to mid-October. Sockeye fry emerge from redds in March-May, depending on whether they are interior or outer coast populations, at which time they generally migrate either downstream (for lake inlet populations) or upstream (for lake outlet populations) to a nursery lake where they spend 1-3 years rearing before initiating seaward migration. During lake residence, sockeye principally occupy offshore waters and commonly exhibit daily vertical migrations from deep-water refuges during the day to near surface waters at night where they feed primarily on pelagic zooplankton but also on chironomids and aquatic insects. Thus, sockeye are the only species of Pacific salmon in PNCIMA that make extensive use of the offshore habitats and zooplankton prey found in the many lakes of the region. After 1-3 summers rearing in fresh water, sockeye migrate seaward during the interval from early April (southern PNCIMA) to late May (northern PNCIMA).

During the early portion of marine life, juvenile sockeye generally move northwestward at rates of 6-7 km per day. Consistent with their freshwater diets, sockeye consume zooplankton (copepods, euphausiids), small larval fish, and occasionally amphipods during early marine life. Comparative studies of the diets of sockeye, chum, and pink salmon during early marine residence suggest that, although many food categories are shared, each species tends to concentrate on different prey, resulting in a broader utilization of the full spectrum of foods in estuarine and continental shelf waters than would occur otherwise. By the fall of their first sea entry year, juvenile sockeye from PNCIMA have largely cleared the area for the coastal waters of southeast Alaska and later the GOA (Hartt and Dell 1986). Sockeye salmon spend 2-4 summers at sea before returning as adults (ages 3-6) to spawn in fresh water. Both adult and juvenile sockeye salmon exhibit very high levels of homing to their natal spawning and lake-rearing areas and consequently exhibit enough reproductive isolation that populations in each lake and river complex exhibit distinctive, behavioural, morphological, and genetic differentiation (Nelson *et al.* 2003).

4.1.4 Coho Salmon

After chinook and chum, coho salmon (*O. kisutch*) are the third largest species of Pacific salmon (2.5-5 kg) and coho weighing up to 6 kg are not uncommon. Although the latitudinal expanse of coho salmon in North America is similar in magnitude to species such as sockeye, chum, or pink salmon, coho salmon are more tolerant of conditions found in watersheds further to the south (*e.g.,* as far south as the Sacramento R. in California) than the former species. In PNCIMA, as elsewhere, a multitude of small populations spawn and rear from 1-3 years in small headwater tributaries to side-channel habitats of river mainstems. Coho salmon are powerful swimmers and excellent jumpers that readily surmount small waterfalls, beaver dams and velocity barriers to penetrate high into the headwaters of small, often ephemeral tributary streams. Coho salmon are less likely than other species to spawn as large aggregates but more often as solitary pairs in pockets of gravel dispersed among large boulders in headwater areas of hundreds of small streams.

The peak of coho salmon returns to coastal waters and rivers of PNCIMA occurs in August to September but both return timing and spawning are often protracted enough that coho salmon comprise the last of several waves of salmon species moving upriver in association with early winter rains. Coho fry emerge from redds in March and April at which time they disperse downstream and into side-channel and off channel habitats to rear. Juvenile coho salmon may spend 1-3 years rearing in stream and side-channel habitats with an abundance of pools and woody debris for cover. Juveniles of some populations also rear in the littoral zones of lakes, but only rarely use offshore waters in such locations, and never in the presence of planktivorous species such as sockeye salmon. Juvenile coho diets in fresh water are commonly dominated by terrestrial insects and a wide range of stream invertebrates. After 1-3 years in fresh water, coho salmon migrate to sea where they feed principally on fish and a wide range of marine invertebrates. Coho salmon commonly exhibit less extensive marine migrations than pink, chum, or sockeye salmon and spend more time in inshore coastal waters closer to their watersheds of origin. Coho salmon spend 1-2 summers at sea usually returning as 2-3 year-old adults to spawn in fresh water. Adult and juvenile coho salmon exhibit higher straying rates from their natal streams for both spawning and freshwater rearing than sockeye, chinook, or chum salmon. Consequently, dozens to hundreds of small populations of coho salmon in a given region may be closely related and form a single large meta-population exhibiting little genetic differentiation among many watersheds.

4.1.5 Chinook Salmon

Chinook salmon (*O. tshawytscha*) are by far the largest of the Pacific salmon (routinely 5-11 kg). The latitudinal extent of chinook salmon is such that the populations in PNCIMA fall roughly in the middle of the range for this species. Chinook salmon spawning aggregations occur principally in mainstem rivers and they may exhibit multiple timing groups such that in the largest river basins (*e.g.,* Skeena, Nass) there are some adult chinook returning in most months of the year. However, peak returns usually occur between May and September.

Although the life history patterns of chinook salmon are highly varied, two basic life history types are differentiated by the temporal duration of freshwater rearing. Stream-type chinook salmon rear as juveniles for up to 2 years in fresh water before migrating to sea. In PNCIMA most stream-type chinook originate from large, interior river basins (*e.g.,* Skeena R., Nass R.) where spawning and rearing habitats are influenced by continental climates characterized by warm, dry summers and cold winters. By contrast, within a few weeks to months of fry emergence, ocean-type chinook salmon migrate to sea from their home rivers and then spend 4-5 years rearing in marine waters where they may either undertake extensive migrations or alternately remain close to their watersheds of origin. Chinook populations originating from the smaller river systems scattered along the coast of PNCIMA are generally ocean-type.

Chinook salmon fry feed on a wide range of terrestrial insects and aquatic insects when rearing in fresh water, but become highly piscivorous at larger sizes during their period of marine rearing. Chinook have one of the lowest straying rates of any of the species of Pacific salmon and accordingly exhibit high levels of behavioural, morphological, and genetic differentiation among widely scattered populations (Figure I.2f).

4.1.6 Steelhead Salmon

Steelhead salmon (*O. mykiss)* vary greatly in size (routinely 2.5-9 kg). They exhibit the most southerly coastal distribution among Pacific salmon in the eastern Pacific such that their populations in PNCIMA fall principally in the northern half of the range for this species. Thus, although there are significant populations of steelhead returning to the Skeena River mainstem and its tributaries, there is little evidence of large populations of this species further north in any of the major rivers of southeast Alaska. Steelhead salmon live for 4-7 years and, by contrast with other Pacific salmon, may spawn in each of several years of their adult life. Steelhead salmon adapt to a variety of conditions and utilize all parts of a river basin, from small tributary streams to mainstem river channels (Augerot *et al.* 2005). Their life histories vary widely and include diverse combinations of fresh water, estuarine, and marine residence. However, in general, their populations are quite small. Adult steelhead salmon are common to many rivers of PNCIMA and return over a protracted period during both summer (*i.e.,* summer-run) and winter (*i.e.,* winter-run) with spawning taking place for both run-timing groups from late winter to late spring. Steelhead complete extensive ocean migrations but because of their relative scarcity, details of their life histories are more fragmentary than for the other species of Pacific salmon.

4.2 The Habitat Context for Salmon in PNCIMA

British Columbia's PNCIMA covers the coastal waters, islands, and watersheds of the Canadian Pacific from the Alaskan border south to Johnstone Strait and from the summits of the Coast Mountain range west to the continental slope. It includes Haida Gwaii/Queen Charlotte Islands (QCI) and northern Vancouver Island. Considered from the perspective of Pacific salmon, the region consists of a Large Aquatic Management Area (LAMA) containing a complex of freshwater habitats scattered across a 118,000 km^2 landscape (more than twice the size of Belgium) and a large ocean management area (LOMA) defined by scores of estuaries, fjords, and open continental shelf seascapes covering 107,000 km^2. The region is in the heart of the Northeast Pacific archipelagic coast, and globally is one of only two large glaciated coastal realms (the other being southern Chile).

4.3 Salmon Habitat and Eco-zones in the LAMA

The LAMA portion of PNCIMA is varied, consisting of lowlands, intricate coastlines, extensive floodplains, and coastal mountain ranges with deeply incised valleys and steep-sided fjords. The climate is cool (mean annual temperatures range from 5°C to 10°C) and wet (mean annual precipitation ranges from 1,000-4,500 mm). The LAMA divides into four broad regions - Lowlands, Haida Gwaii Insular Mountains, Outer Coast Mountains, and Inner Coast Mountains - differing in topography, climate, hydrology, natural disturbance regimes, and ecosystems (BC Coast Information Team 2004). Trainor (2001) provides a map and describes the existing biogeoclimatic and physiographic boundaries that delineate the four regions.

The Lowlands form narrow, low lying, boggy strips along the coast and islands. Precipitation is high, but annual snowfall is relatively low. The Insular, Outer Coast, and Inner Coast Mountain regions all feature steep, rugged mountains, ocean fjords, and watersheds of variable size. These mountainous regions are distinguished primarily by climate: the Insular Mountains are very wet and cool with little snowfall, the Outer Coast Mountains are very wet and mostly cool with heavy snowfall, and the Inner Coast Mountains are drier with warmer summers and heavy snowfall. The four major regions can be further subdivided into at least 11 sub-regions according to glacial runoff and hydrology (BC Coast Information Team 2004). Thus, rivers and watersheds with hydrology dominated by snowmelt (*e.g.,* Nass, Skeena, Kitlope) exhibit minimum flows from December to January and peak flows from June to July. By contrast, Lowland and Outer Coast watersheds with rainfall dominated hydrographs (*e.g.,* Yakoun, Copper, Keogh, Nimpkish) exhibit peak flows from November to January and minimum flows from August to October (Farley 1979).

The LAMA portion of PNCIMA includes 45% of North America's three temperate, rainforest ecoregions and contains the largest remaining expanses of intact temperate rainforest in the world (BC Coast Information Team 2004). Natural disturbances, along with the activities of First Nation's peoples, have historically shaped the composition and structure of these forests that play a major role in controlling the structure and ecological processes that influence both the quantity and quality of habitat used by Pacific salmon throughout the area. Natural disturbances that replace forest stands in the LAMA are rare, so old growth forest (and relatively stable biological communities) dominates valley bottoms, riparian corridors, and the lower slopes of mountain areas.

Geomorphic disturbances, such as landslides and snow avalanches, are the primary natural agents of stand-replacing disturbance in wet, steep coastal forests. Wind (generally restricted to the exposed portions of the Insular Mountains and northern Vancouver Island) and fire (generally restricted to the Inner Coast Mountains) may also occasionally create large openings in the forest canopy of the LAMA. Return intervals for these stand-replacing events are on the scale of millennia throughout the majority of the area. Flooding is a key process shaping floodplains, river-fans and estuaries, which are highly productive biodiversity hot spots (BC Coast Information Team 2004). The different types of disturbance do not occur homogeneously across the forest landscape, with the result that a forest mosaic has emerged consisting of large, continuous tracts of all-aged, structurally diverse old-growth forest composed principally of western hemlock and, in wetter lowland areas, red cedar. Pearson (2003, cited in BC Coast Information Team 2004) found the area of forest land disturbed in a Central Coast study plot over the past 140 years amounted to only 0.3%, 1.4% and 1.3% of the total area from wind, geomorphic (*i.e.,* landslides, avalanches, and flooding), and fire disturbance-events respectively. Fire was limited to the Inner Coast Mountains, wind was limited to the Lowlands, and geomorphic disturbances occurred throughout the area.

Within the LAMA portion of PNCIMA, the Coastal Western Hemlock and Mountain Hemlock biogeoclimatic zones cover about 80% of the landscape. Moreover, in this wet, cool coastal environment, hydroriparian ecosystems commonly utilized by Pacific salmon are particularly prevalent. In the Lowlands, wetlands (bogs, ponds, and small lakes) cover 51-75% of the landscape (Banner *et al.* 1986; 1988 cited in BC Coast Information Team 2004). Small, low-gradient streams are very common, draining extensive slope/blanket bogs. There are many small but few large estuaries and floodplains, because Lowland watersheds are small and primarily rain fed. Exposed marine shores are common. The Insular and Coast Mountains contain a variety of hydroriparian ecosystems, including small, steep headwater streams and gullies, running down into fans and floodplains. Moderately sized lakes head some valleys and a variety of small wetlands dot floodplains. In these mountainous regions, large estuaries fed by rivers (*e.g.,* Skeena, Nass, Bella Coola, Kitimat, Kitlope), rain, glaciers, and permanent snow are common. Because of their diverse forms, relatively frequent disturbance and high productivity, hydroriparian ecosystems throughout PNCIMA are home to distinctive assemblages of plants and animals and are hotspots of regional biodiversity. However, in general, biological communities of the LAMA exhibit considerable stability over centuries of time with respect to dominant forest cover (*e.g.,* old growth hemlock, cedar, and fir) that plays a major role in shaping both the quality and quantity of habitat available for various species of Pacific salmon.

4.4 Salmon Habitats of the Marine Portion of PNCIMA

The oceanic portion of PNCIMA is a submarine continuation of the LAMA known as the Queen Charlotte Basin (QCB) which can be considered a semi-enclosed sea (see Chapter 1: Ecosystem Description, Appendix A: Geology, and Appendix B: Meteorology and Climate). At its northern end, the QCB connects to the offshore via Dixon Entrance. The central portion of the basin, known as Hecate Strait, is relatively protected from the open NE Pacific by the Queen Charlotte Islands. Further south, the basin is more exposed, and is contiguous with the offshore NE Pacific via Queen Charlotte Sound. Thomson (1981) notes that from an oceanographic point of view, the QCB is a hybrid region, similar in many respects to the nearby offshore waters of the Pacific but considerably modified by estuarine processes characteristic of protected inland coastal waters. Ware and McFarlane (1989) considered the QCB to be part of the Coastal Downwelling Domain (CDD) extending from Queen Charlotte Sound to the Aleutian Islands. The prominent circulation features in this region are the poleward flowing Alaska Current, and Alaska Coastal Current, where the latter is driven by freshwater runoff in northern BC and southeast Alaska. The Alaska Coastal Current extends seaward about 40 km from the coast, flows at an average speed of some 20 km d^{-1} and links conditions in the QCB to conditions and events in the Gulf of Alaska where most sockeye, pink, and chum salmon populations spend 1-3 years rearing following their northwesterly migration through the QCB during their first year of sea entry. See Appendix C: Physical and Chemical Oceanography for more about ocean currents influencing PNCIMA.

The diverse marine habitats that salmon utilize in the QCB are created by complex, seasonal interactions among bathymetry, wind, freshwater runoff, and tidal currents that control both the circulation of water and its properties within the QCB (Thomson 1981). Although the detailed patterns of salmon utilization of these varied marine habitats are less well studied than their use of freshwater habitats, several generalizations are possible. From a salmon habitat perspective, the waters of the QCB may be viewed as consisting of: (1) transitional, estuarine staging, and rearing areas for the juvenile and adult stages of all species (*e.g.,* coastal inlets and major estuaries of the Nass and Skeena rivers); (2) upwelling areas of productive underwater shoals and banks that are especially important as rearing areas for aggregations of sub-adult coho and chinook salmon (Dogfish, North Island, Goose, and Cook banks); (3) continental-shelf, surface-water eddies that may entrain juvenile salmon and plankton for periods of days to weeks (*e.g.*, clockwise rotating Rose Spit Eddy and the counter-clockwise flowing Queen Charlotte Sound Eddy, Crawford *et al*. 1995); and (4) advection zones along the continental shelf where surface waters may move rapidly seaward as filaments or plumes with replacement from depth by upwelling nutrient rich waters. Historic surveys of the distribution and abundance of juvenile salmon suggest differential use of these areas across seasons (Hartt and Dell 1986). Thus, in early spring and summer, juveniles of all species are found aggregated in nearshore inlets and estuaries serving as their points of sea entry (*e.g.,* Skeena, Nass, Bella Coola, etc.). However, by October, juvenile salmon of all species are found somewhat further offshore concentrated in pelagic, surface waters (<50 m) located between the 100 m and 1000 m isobaths over the continental shelf (Figure I.8, after Welch *et al.* 2007). All Pacific salmon species, whether rearing in or migrating through the QCB, tend to aggregate in near-shore waters of the continental shelf. The virtual absence of juvenile salmon in offshore waters of PNCIMA (Figure I.8) underscores the importance of near-shore areas to salmon populations originating from watersheds within and external to the QCB.

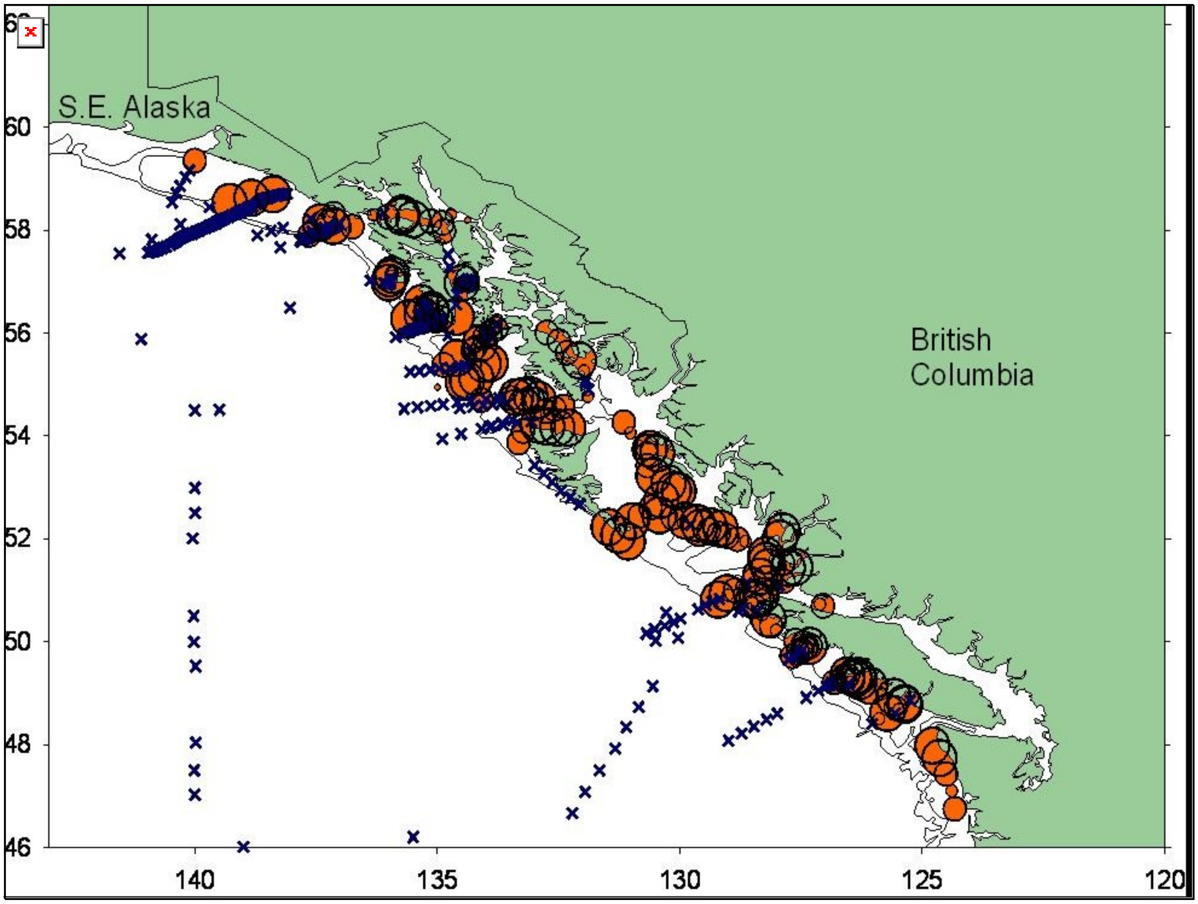


Figure I.8 Distribution of juvenile salmon catches of all species off the west coast of North America in October (all species combined). The size of circles is proportional to the number of fish caught (smaller means fewer). The Xs represent locations fished without catching salmon. The 200 m and 1000 m isobaths are indicated (from Welch *et al.* 2007).

Conditions (current fields, thermal regimes, salinity gradients, prey density, etc.) encountered by salmon in the marine habitats of the QCB are dominated either directly or indirectly by powerful but remote climate systems (see Appendix B: Meteorology and Climate). The latter are controlled in fall and winter by the Aleutian Low and in spring and summer by the North Pacific High that influence seasonal and annual to multidecadal variations. In contrast with the relative stability of habitats and biological communities observed over centuries of time in the LAMA, habitats and biological communities in marine portions of the QCB exhibit much more variation where sudden shifts in atmospheric forcing over either the subtropical or North Pacific are linked to rapid changes in upper ocean conditions and the organization of biological communities. Thus, El Niño Southern Oscillation (ENSO) episodes off of Peru are associated with intensification of the Aleutian Low and westerly winds at mid-latitudes in the North Pacific, leading to a stronger than normal poleward advection of warm water along the coast of North America every 7-12 years on average (Ware and McFarlane 1989). Similarly, a reversal of these conditions to a relatively cold La Niña state frequently appears immediately after major ENSO events. Zooplankton standing stocks in the QCB dropped steeply during the 1997 El Niño event. Similarly, El Niño-La Niña episodes appear to influence the distribution and abundance of large migratory hake in the QCB such that they are abundant in warm El Niño years but virtually absent in cool La Niña years (Cooke in Department of Fisheries and Oceans 2006). In addition, although the causal mechanisms are poorly understood (Schwing *et al.* 2005), statistical analyses of Pacific Ocean and atmosphere fields for the twentieth century have revealed spatial patterns that remain relatively steady for 10-30 years (regimes), followed by a rapid change or "regime shift" within a few years to another relatively stable pattern (various authors in King *eds*. 2005). Evidence suggests the occurrence of climate regime shifts in 1977, 1989, and 1998 in the North Pacific. Thus, after 1977, the Aleutian Low intensified, resulting in a stronger Alaska Current, warmer water temperatures, increased coastal rain, and increased water column stability.

A doubling of zooplankton biomass between the 1950s-60s and in the 1980s indicates that production was positively affected after the 1977 regime shift (Brodeur and Ware 1992) and accompanied by improvements in recruitment and survival of salmon in the Gulf of Alaska and northern portions of the QCB. By contrast, the 1989 regime shift was accompanied by cooler waters and more variable conditions in the Gulf of Alaska, and survival of at least some of the salmon stocks in the QCB (*e.g.,* several sockeye and pink salmon populations in the Central Coast) plunged steeply along with declines of QCI herring stocks (Boldt *et al.* 2005). The mechanisms controlling these periodic physical and biological changes in the eastern Pacific and QCB do not fit neatly into the concept of inverse production regimes suggested by Hare *et al.* (1999) for northern versus southern salmon stocks. However, it is highly likely that similar large-scale, but poorly understood oceanic production processes play important roles in determining seasonal to annual variations in patterns of habitat use, ecosystem structure (see examples in DFO 2006), and recruitment variations of salmon in the QCB.

4.5 Ecologically or Biologically Significant Areas (EBSAs) for Salmon in PNCIMA

The species and impressive life history diversity documented for Pacific salmon have allowed them to utilize a broad range of habitats that define both a large aquatic management area (LAMA) and a large oceanic area within PNCIMA. Salmon habitats of the LAMA extend from the interior of major river basins such as the Skeena, the Nass, and the Bella Coola through the medium sized rivers, lakes, and small streams of a significant portion of the watersheds lying west of the Coast Mountains to watersheds scattered throughout the Queen Charlotte Islands and the northern end of Vancouver Island. Salmon habitats of the oceanic area encompass marine waters of Johnstone Strait on the southern end of PNCIMA through the coastal fjords and inlets plus the broad continental shelf comprising Hecate Strait and Queen Charlotte Sound to Dixon Entrance in the north. As noted earlier, an average of 25-30 million adult salmon return to spawn annually in the watersheds of the PNCIMA area. Assuming an all-year, average, marine survival rate of roughly 4% among all species of juvenile salmon from the time of sea entry to return as adults (Bradford 1995) suggests that 625-750 million juvenile salmon may enter PNCIMA from its tributary watersheds each year. In addition to this, it is likely that, in aggregate, more than twice this many adult and juvenile Pacific salmon originating from or returning to more southerly coastal watersheds (*e.g.,* those of Georgia Basin, Puget Sound, Fraser Basin, coastal Washington, Oregon, and California) pass through PNCIMA coastal waters.

Although the detailed migratory routes and timing variations of individual stocks and species are known in only the most general terms, it is clear that key zones of egress and ingress (potential EBSAs) may be initially identified in association with the watersheds within PNCIMA that support the largest populations of salmon (Figures I.2a-f). The distribution and abundance of spawning salmon may be used as a crude, first approximation of the relative importance of key marine zones in PNCIMA for actively migrating juvenile and adult salmon. Thus, the waters of Dixon Entrance are a key zone that hosts annual migrations of large populations of migratory juvenile and adult salmon originating from large river systems such as the Nass and Skeena. In addition, coastal areas proximal to the Bella Coola and Atnarko rivers or Smith and Rivers inlets north of Johnstone Strait may be considered to be especially important potential EBSAs. Similarly, Johnstone Strait and Dixon Entrance are obvious areas of high sensitivity because salmon migratory behaviours, ocean currents, and coastal landforms combine to disproportionately concentrate juvenile and adult salmon originating from watersheds to the south as they pass through PNCIMA waters on their northward migrations in spring and southern migrations in summer through fall respectively. For salmon species such as coho and chinook that are more likely to reside for prolonged periods in PNCIMA, areas of high biological production near banks and shoals will serve to attract aggregations of rearing juveniles and so may be regarded as especially sensitive to disturbance. For example, there is evidence that the shoal-region centered on Juan Perez Sound on the southeast side of Moresby Island is a "hot spot" for biological production for many species in the southern QCB (Royal Society of Canada 2004) and thus it is not unexpected that several species of juvenile salmon also concentrate in this area (Figure I.8).

5.0 ECOSYSTEM LINKAGES FOR SALMON

5.1 Large Aquatic Management Area (LAMA)

The coastal strip of PNCIMA between Knight (lower Area 12, Figure I.6a) and Portland inlets (Area 3, Figure I.6a) has been called one of the few remnants of fully functioning rainforest in North America (McAllister *et al.* 1997; BC Coast Information Team 2004). Large populations of grizzly bears (BC government estimates of between 1500 and 3000; BC Coast Information Team 2004) along with 230 bird species, 68 species of mammals and thousands of insect species define a wildlife complex and level of biodiversity that ranks high enough among global sites for biodiversity that it has been compared to Africa's Serengeti Ecosystem (Reimchen pp. 93-96 in Harvey and MacDuffee 2002).

Ecological theory holds that certain animals exert a disproportionate influence on the ecosystems in which they live. Paine (1969) introduced the term “keystone species” to describe animals that, through their activities and abundances, regulate the productivity, diversity, or physical structure of their communities, with influences extending beyond those organisms directly affected through trophic interactions. Implicit in the concept is that keystone species are exceptional in their importance relative to the rest of the community (Mills *et al.* 1993), that they are unique in their functioning within the community, and that their impacts are disproportionately large relative to their abundances (Power *et al.* 1996). Loss of a keystone species results in significant changes in the structure or organization of a given ecosystem, with adverse consequences for the survival of other native species or populations (Helfield and Naiman 2006). Pacific salmon are commonly regarded as a keystone species in coastal ecosystems because of their importance as a limiting food resource for a diverse assemblage of vertebrate predators and scavengers (Willson and Halupka 1995; Willson *et al.* 1998; Cedarholm *et al.* 2000) and because of their importance as delivery agents for scarce nutrients (*e.g.,* phosphorus and nitrogen; Gresh *et al.* 2000) that commonly limit production at the base of the food-web in freshwater ecosystems throughout the eastern Pacific Rim including the LAMA (Stockner and Shortreed 1985; Hyatt and Stockner 1985; Hyatt *et al.* 2004a; 2004b).

Spatial and temporal variations in the abundance of spawning salmon can have major effects on the dynamics of wildlife populations and on maintenance of regional biodiversity (Willson and Halupka 1995). For example, Cedarholm *et al.* (2000) documented over 137 species of vertebrates, in addition to many invertebrates, which use salmon as a food source. Studies of ecological interactions between salmon and bears demonstrate just how critical these interactions with wildlife may be. Studies of southeast Alaskan coastal brown bears suggest that almost all of their carbon and nitrogen is obtained from salmon and that a correlation exists between the autumn mass of female bears and their reproductive success (Hildebrand *et al.* 1996). Consequently, it is not surprising that when sockeye salmon populations in the Rivers Inlet area of the LAMA virtually collapsed in 1999 that both grizzly and black bears were observed to be starving and several had to be shot as nuisance animals after their fall salmon food supply failed to appear (S. Bachen, DFO, Campbell River, pers comm., 2000). Indeed, the generally greater abundance of salmon appears to be the main reason for the maintenance of much higher densities of carnivores and scavengers in coastal as opposed to interior ecosystems (*e.g*., bears are 6-80 times more abundant on the coast, Miller *et al.* 1997; see also Reimchen 2000).

The impact of large numbers of salmon returning to spawn in coastal ecosystems is not limited to just their direct consumption by carnivores and scavengers. Stable isotope analyses of sediment cores from Alaskan lakes (*e.g.,* Finney *et al.* 2000; Gregory-Eaves *et al.* 2003) have provided results to suggest that variations in sockeye salmon escapement and carcass deposition have a long term impact on variations in phosphorous (P) and nitrogen (N) delivery that influence subsequent variations in the productivity of nutrient poor lakes. Similarly, stable isotope analyses of plant communities adjacent to spawning streams suggest that riparian plants may derive as much as 18-60% of their foliar N from marine derived nutrients (MDN) imported from the high seas by spawning salmon (reviewed in Nelitz *et al.* 2006). Accordingly, variations of salmon returns in both space (Figures I.2a-f) and time (Figure I.4) will not only influence aquatic ecosystems throughout the LAMA but will also have significant effects on the structure, growth, and productivity of riparian vegetation (Naiman and Latterell 2005).

Naiman and Latterell (2005) have provided an initial synthesis of how interactions between carnivores/scavengers and salmon may affect the cycling of MDN to shape not only river and riparian ecosystems but also the long term viability of the contributing salmon populations. Adapting their work here (Figure I.9), bears and other piscivores consume Pacific salmon, spreading salmon-enriched wastes and partially-eaten carcasses into freshwater and riparian-zone habitats. Terrestrial and aquatic insects colonizing the carcasses enhance decomposition and diffusion of MDN. In the riparian forest, MDN are first re-mineralized by bacteria and then taken up by vegetation, increasing foliar N content and growth rates. Large riparian trees provide bank stabilization, shade, inputs of organic matter, and large woody debris (LWD) thus improving the quality of instream, salmon habitat. LWD retains post-spawn, salmon carcasses in streams, further enhancing MDN availability. Increased foliar N content enhances palatability and nutrition of riparian plants, potentially altering patterns of browsing by wildlife. This may affect patterns of riparian plant productivity and species composition. The net result is a positive feedback loop that enhances the strength of ecosystem linkages, ecosystem-scale productivity, and biodiversity (Figure I.9) as long as keystone interactions between bears and salmon remain functional. By contrast, external events that result in major reductions of salmon and/or bears (*e.g.,* climate induced mortality or harvest of one or both) have the potential to disrupt many of these processes, thus weakening ecosystem linkages (Figure I.9) and ultimately the feedback effects these have on ecosystems, salmon, and bears.

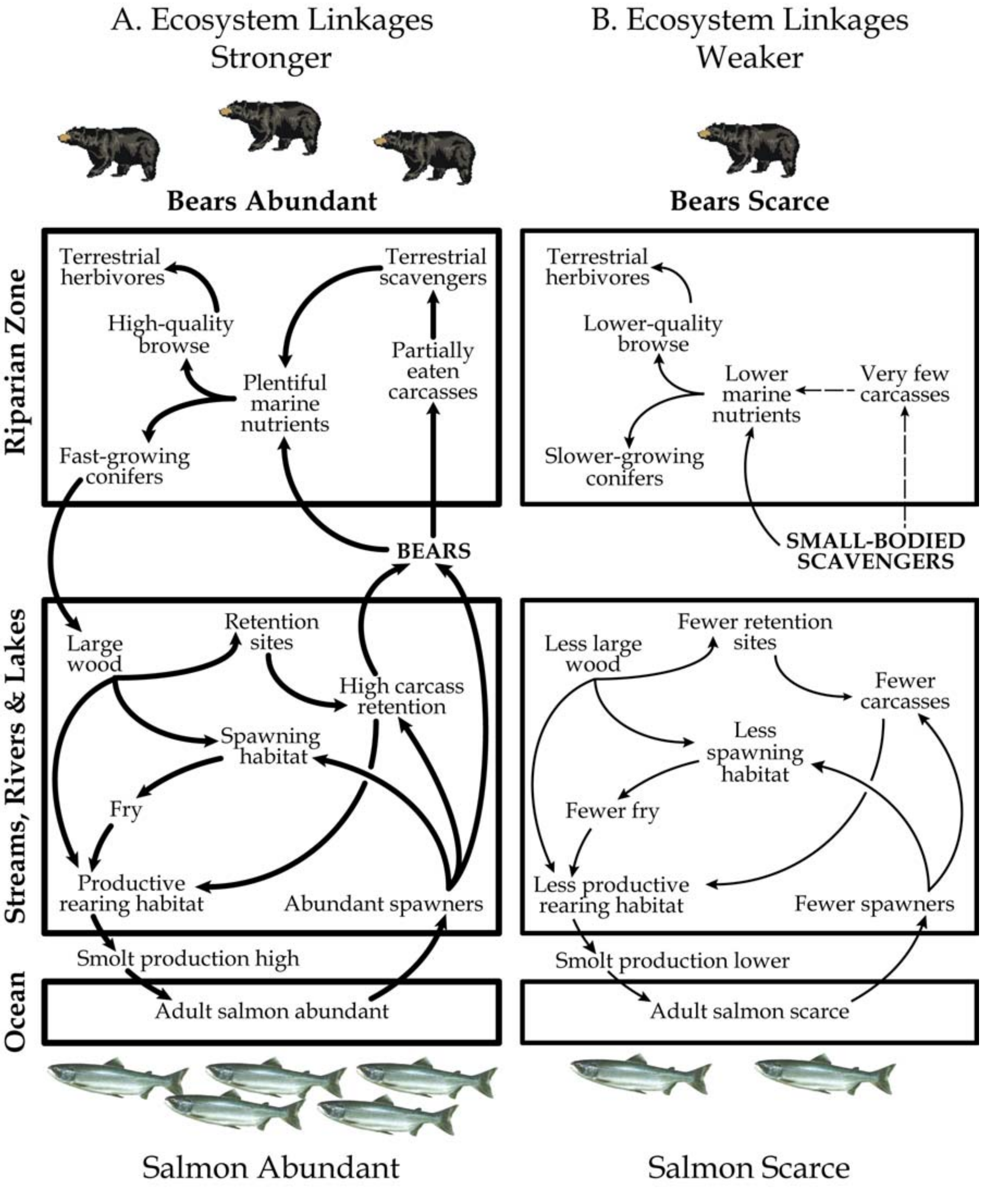


Figure I.9 A conceptual summary of the interactions among salmon and bears, acting as keystone species, in freshwater and riparian ecosystems of PNCIMA. A. Ecosystem linkages among many elements are strengthened when both salmon and bears are abundant; and B. Ecosystem linkages become much weaker and, in some cases, may be severed if bears or especially salmon become scarce. See text for details (figure modified from Naiman and Latterell 2005).

Anadromous salmon may act as important agents for delivery of critical nutrients (*e.g.,* phosphorus, nitrogen, and trace minerals) that control production at the base of food webs in many watersheds (Gresh *et al.* 2000), but this role is unlikely to be of uniform importance in all watersheds. Although inorganic phosphorus is known to commonly limit primary production by algal communities in coastal streams, rivers, and lakes (Stockner and Shortreed 1985; Hyatt and Stockner 1985; Hyatt *et al.* 2004b), examination of regional distributions of total dissolved solids in hundreds of aquatic habitats suggests that the distribution of nutrients, including inorganic phosphorous, is not uniform throughout the LAMA (Figure I.10). Thus, watersheds aggregate into clusters that exhibit varying levels of nutrient concentrations supporting a range of inherent productivity differences at sub-regional scale. Watersheds clustered in the area of Pitt, Banks, and Princess Royal islands bordering the central portion of the mainland of the LAMA appear to be especially nutrient poor (Figure I.10) while those clustered in the headwaters of the Dean, Bella Coola, Nimpkish (N. Vancouver Island), and Yakoun (QCI) rivers appear somewhat less nutrient impoverished (see Hyatt *et al.* 2004a; 2004b). These patterns may be explained in terms of differences in regional bedrock geology which, in combination with the erosive forces of weathering, influence annual to seasonal patterns of inorganic nutrient and mineral loading within various watersheds of the LAMA. Thus, the watersheds exhibiting higher total dissolved solids (TDS) values noted above (*e.g.,* the Dean, Bella Coola, Yakoun, Nimpkish, etc.) are underlain by mixtures of sedimentary and volcanic rock which provide higher inorganic nutrient concentrations than those present in other coastal watersheds (*e.g.,* Princess Royal, Pitt, and Banks) dominated by nutrient poor, granitic rock and crystalline gneiss (Farley 1979, p.29).

These differences alone help explain, in part, why the long term production of all salmon originating from the Pitt, Banks, and Princess Royal Island area watersheds is lower than the aggregate production observed in other areas of similar size (Figures I.2a-f). In theory, this may be relevant to interagency responsibilities for maintenance of regional biodiversity in this portion of the LAMA where the government of BC recently designated selected watersheds in and around Princess Royal Island as the Kitasoo Spirit Bear Protected Area (February 2006) for conservation of culturally significant Kermode bears (Russell 1994; McAllister *et al.* 1997). These observations are significant to the development of ecosystem based management principles for application to wild salmon populations because they indicate that the disruption of nutrient delivery by salmon to watersheds due to commercial harvest of salmon will involve a range of consequences that may vary in severity from area to area depending on a host of interacting factors (see also Gresh *et al.* 2000; Nelitz *et al.* 2006).

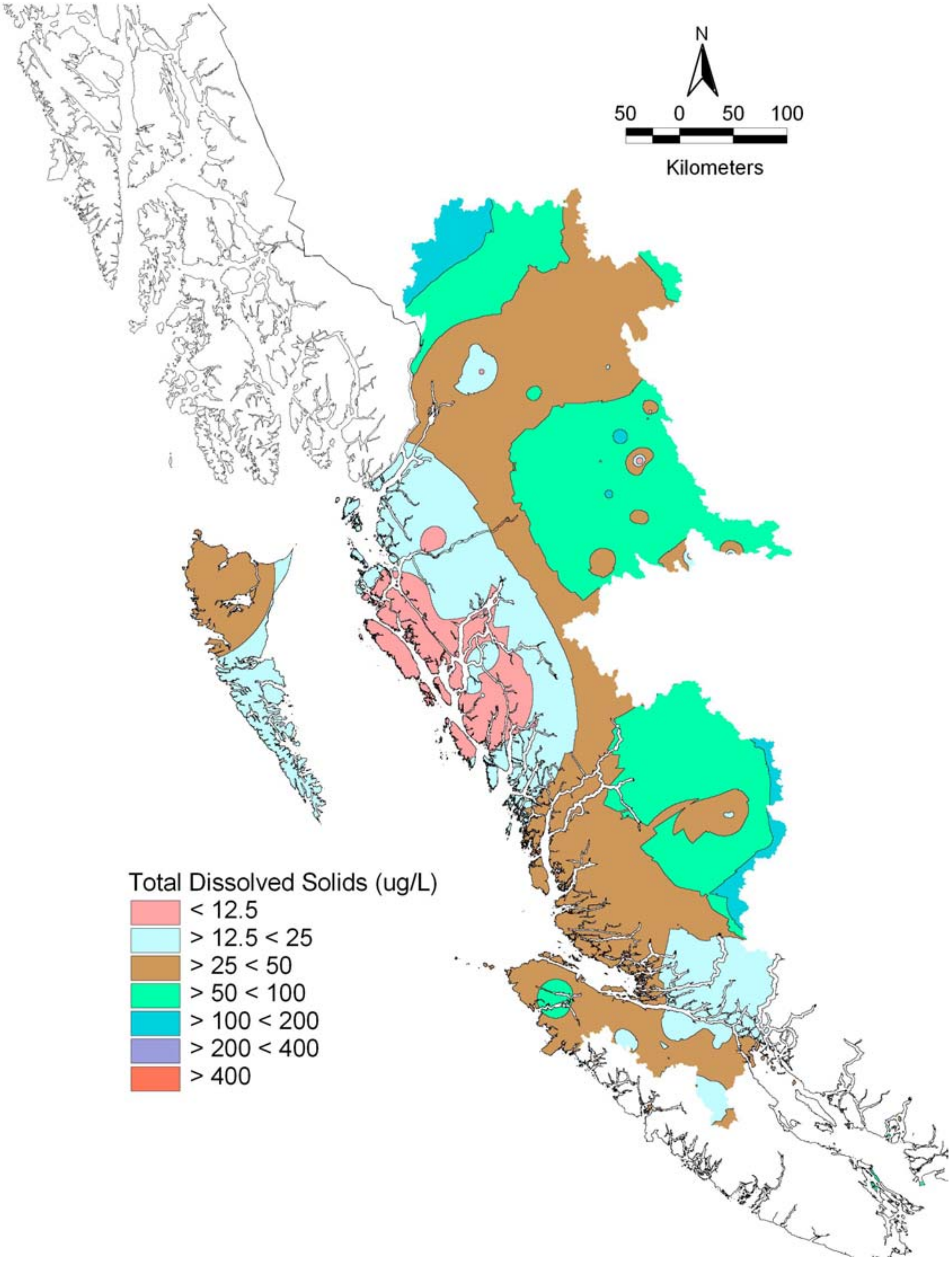


Figure I.10 A summary of spatial patterns of total dissolved solids (TDS) present in freshwater rivers and streams sampled in hundreds of locations throughout the PNCIMA portion of British Columbia. Note unequal classification intervals from the low to high end of the scale. TDS observations from BC Ministry of Environment. TDS categories and figure format developed by Hyatt *et al.* (this report).

5.2 Queen Charlotte Basin (QCB)

Long term (1900-2000) average catches of all salmon species in the QCB amount to less than 30,000 tonnes yr^{-1} (Figure I.5). Given that catches of salmon throughout this interval have, on average, amounted to no more than 50% of production, it would appear that total salmon biomass originating in the QCB amounts to no more than 60,000 tonnes per year. Furthermore, the latter figure may not fairly represent the quantity of Pacific salmon actually produced in the QCB because: (1) sockeye, pink, and chum salmon, by far the most abundant species, spend the majority of their lives in offshore pelagic waters of the Gulf of Alaska and only relatively brief periods rearing in coastal areas of the QCB as much smaller juveniles and returning adults; and (2) a portion of the salmon catch landed by commercial fisheries in the QCB consists of interceptions of southern stocks migrating through the area (*e.g.,* Fraser R., mainland inlets, west coast Vancouver Island).

By contrast, Ware and McFarlane (1989) noted that resident stocks of chinook and coho salmon in the QCB portion of the Coastal Downwelling Domain accounted for less than 35 tonnes of biomass while herring stocks alone accounted for an average biomass of nearly 180,000 tonnes. Thus, Pacific salmon do not function as ecological keystone species in marine environments of the QCB to the extent that they do in freshwater and hydroriparian ecosystems of the LAMA noted above. This is not to say that Pacific salmon are unimportant in marine ecosystems but rather that their importance is more likely to depend on the occurrence of specialized ecosystem linkages to other marine species (*e.g.,* Cedarholm *et al.* 2000) rather than as a causal agent of more systemic ecosystem processes. For example, Ford *et al.* (1998) have noted that from April to October, resident orcas (*Orcinus orca*) congregate in areas such as Johnstone Strait at times that correlate with seasonal salmon migrations. Further, these authors speculate that specialized foraging strategies have developed within specific pods of whales to correlate with various salmon runs and species (*e.g.,* especially chinook salmon) that, in turn, may determine the long term well being of particular groups of whales.

Although Pacific salmon do not serve as keystone species in the QCB from an ecological perspective, there remains no doubt about their keystone role there from a cultural perspective (*in sensu* Garibaldi and Turner 2004). Given their cultural and economic importance in large ocean management areas, salmon are generally regarded as very important, but complex, indicators of the effects of both natural and man-made disturbances that may create multiple stressors on ecologically and biologically sensitive areas (*e.g.,* EBSAs including points of seaward entry, principal migration corridors, rearing areas, etc.) as well as serving as focal point subjects themselves for biological conservation and sustainable resource use. The latter items in particular have increasingly become focal points for fisheries and species management issues in many regions of the QCB as contemporary fisheries management objectives have evolved from an historic emphasis on maximizing biomass of single species harvest to a more recent emphasis on minimizing loss of biodiversity among multi-species assemblages of commercially exploited Pacific salmon stocks (Hyatt and Riddell 2000). For example, decades of concern over significant bycatch of steelhead salmon (*O. mykiss*) in large commercial fisheries for sockeye salmon (*O. nerka*) in approaches to rivers such as the Skeena and Nass have translated into increasingly stringent area and time constraints on sockeye fisheries to protect the much less abundant stocks of steelhead (Sprout and Kadowaki 1987). Even more recently, additional area and time constraints have been applied to harvest of highly productive sockeye stocks returning to Babine (Skeena R.) and Meziadin (Nass R.) lakes to facilitate conservation and rebuilding of dozens of small, but genetically distinct, sockeye populations that occur as complex mixtures in salmon fisheries throughout the northern portion of the QCB (Fisheries and Oceans Canada 2006).

6.0 ISSUES AND INFORMATION GAPS

Pacific salmon are at once the subjects of one of the most advanced as well as one of the most cumbersome systems of fisheries management anywhere on the globe. Scores of fisheries harvest salmon from hundreds to thousands of populations in PNCIMA alone and have done so for anywhere from a century (contemporary fisheries) to thousands of years (aboriginal fisheries). In spite of this enviable record of success, there are signs that significant changes are required in current-day management practices in order to ensure the long-term sustainability of the salmon stock-and-habitat complex of PNCIMA. Fisheries and Oceans Canada’s new Wild Salmon Policy (WSP; Fisheries and Oceans Canada 2005) identifies a general blueprint for achieving this general goal by focusing DFO and societal efforts on three major objectives, six strategies, and four guiding principles (Figure I.11). Although detailed review of the WSP is not warranted here, a cursory examination will suffice to suggest the types of important issues and information concerns that emerge when considering its application to the salmon stock-and-habitat complex of PNCIMA, as follows.

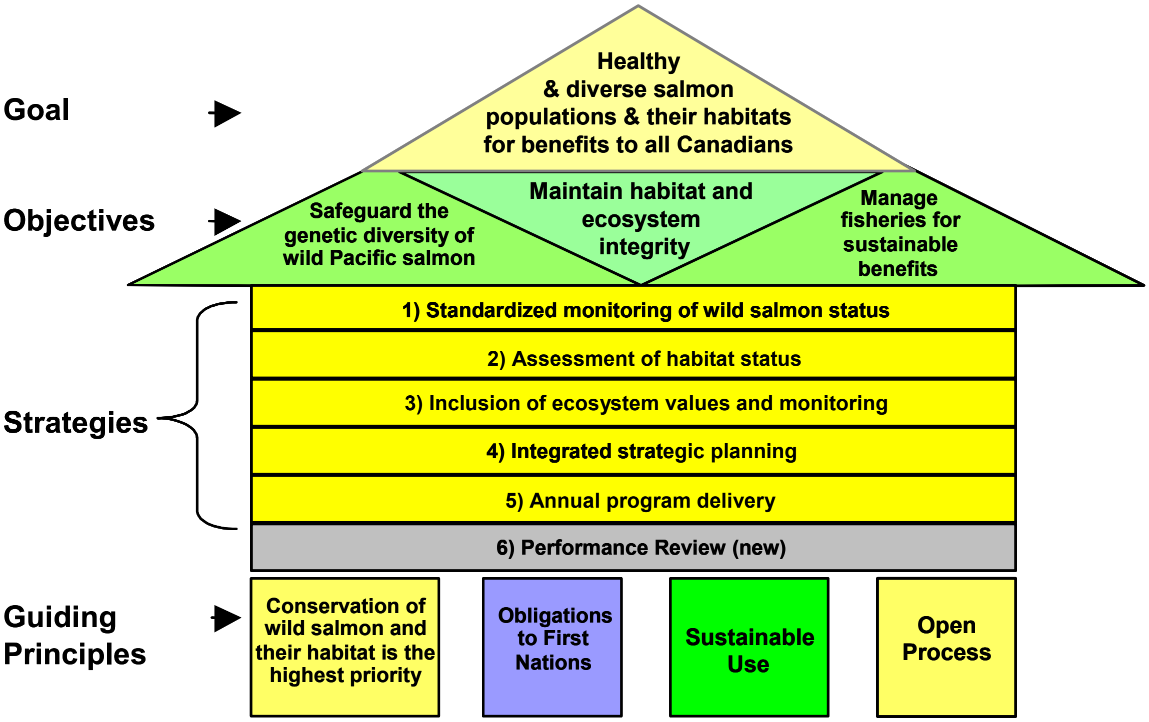


Figure I.11 Structure of Fisheries and Oceans Canada's Wild Salmon Policy including its overarching goal along with specific objectives, strategies, and guiding principles for implementation (adapted from Fisheries and Oceans Canada 2005).

Objective 1 of the WSP (Fisheries and Oceans Canada 2005) is to safeguard the diversity of wild Pacific salmon. Thus DFO intends to maintain the genetic diversity of Pacific salmon through the protection of Conservation Units (CUs) that represent a group of wild salmon sufficiently isolated from other groups that if extirpated is very unlikely to recolonize naturally within an acceptable timeframe (*e.g.,* a human lifespan). Earlier in this report it was noted that different species of salmon display large differences in their genetic affinities such that the number of wild salmon CUs in PNCIMA will vary from hundreds in the case of sockeye, where every lake and river combination will contain a CU, to less than a dozen in the case of pink or coho salmon, where high rates of straying create large, meta-populations of genetically related individuals that simultaneously occupy many streams and rivers spread across appreciable portions of major watersheds (*e.g.,* Upper Skeena). Thus, CUs represent a new conservation focal point around which resource management and stock assessment must be organized. In PNCIMA this is problematic given that historic stock assessments have failed to generate sufficient information to classify the status of more than 40% of all local salmon populations (Slaney *et al.* 1996) including at least 51 of 117 sockeye populations (Riddell 2004) that are likely to be CUs under the WSP. In addition, both the Pacific Fisheries Resource Conservation Council (PFRCC 2005) and other independent observers (Thomson and MacDuffee 2002) noted declines in assessment effort from the 1980s to present to survey salmon populations throughout PNCIMA. Both of the latter studies stressed that historical spawner abundance surveys and data are the base for any future assessments and development of sound conservation strategies.

Objectives 2 and 3 of the WSP are to maintain habitat and also ecosystem integrity because, as described earlier in this chapter, the health and well-being of wild salmon is inextricably linked to the availability of a diversity of interconnected and productive freshwater and marine habitats used by each of the several species throughout PNCIMA. Aquatic habitats and their adjacent terrestrial areas are also valued for a wide range of human activities. Consequently, the integrity of salmon habitat is challenged by human competition for accessible land and fresh water, for ocean spaces and for the interconnecting estuarine and coastal areas that may be utilized for a variety of activities including: urban development, large scale resource extraction, aquaculture, or the industrial-scale manufacture of goods. Given a total human population of less than 100,000 (Prescott-Allen 2005), the sum of these activities in PNCIMA is currently modest by comparison with the state of habitat and ecosystem disruption in salmon bearing systems to the south of PNCIMA (Slaney *et al.* 1996). However, there is a growing appreciation that the relatively undisturbed state of natural ecosystems in PNCIMA has the potential for very rapid change within 1-2 decades in the face of a variety of ecological threats that include: commercial fisheries, accelerating industrial forestry (Harvey and MacDuffee 2002), development of oil and gas resources (Royal Society of Canada 2004), aquaculture development (PFRCC 2002), increased tourism, and outside disturbances such as climate change (Government of British Columbia 2006).

In addition to the obvious threats that human activities pose for the maintenance of productive habitat for Pacific salmon, there is a growing body of credible scientific evidence to suggest that maintenance of habitat and ecosystem integrity also involves a positive feedback loop in which habitat structure and ecological processes are dependent on multiple influences of the salmon themselves (Figure I.9). Consequently, salmon harvest levels, once considered to be a relatively simple exercise involving the removal of adult fish that were surplus to requirements for "seeding" the next generation of returns (*e.g.,* Ricker 1954), have become the focus for debates about tradeoffs between the immediate socioeconomic benefits of harvest versus the longer term ecological benefits of foregoing harvest to maintain key elements of regional biodiversity, habitat productivity, and ecosystem integrity. Thus, Reimchen (pp. 93-96 in Harvey and MacDuffee 2002) has argued that average exploitation rates on salmon are 3-20 times those observed in most natural, multi-predator species communities and suggests that a long term, sustainable harvest rate should not exceed 5% for individual salmon populations!

Although opinions such as Reimchen's may seem unnecessarily Draconian, they do serve to underscore the fact that salmon management has entered a period of increasingly complex and, oftentimes, competing objectives that are unlikely to be satisfied by traditional single species yield or assessment frameworks (Hyatt and Riddell 2000; see also pp. 72-79 of Cedarholm *et al.* 2000). Similarly, spatial and temporal interactions that depend not only on the state of salmon habitat but also on the influence that salmon may exert on the long-term productive capacity of these habitats suggests that the common practice of conducting salmon stock or salmon habitat assessments rather than assessments of the salmon stock-habitat complex will be increasingly inadequate as a basis for sustainable management of Pacific salmon in the future. Reflecting on what this implies about future assessment frameworks to improve management, Cedarholm *et al*. (2000) concluded that managing salmon as keystone species within an ecosystem context will require material, energy, and nutrient budget analyses on appropriate spatial (*e.g.,* PNCIMA, major river basin, sub-basin, stream) and temporal (months to millennia) scales to estimate the effects that land and fisheries resource management practices (past, present, future) have on ecosystems and salmon populations, and that the latter have on ecosystems. Questions that may be posed as relevant to the pursuit of this objective include: (1) what is the status of the inorganic nutrient capital and rates of transport that limit habitat productivity within the various domains of salmon (inorganic nutrient budget)?, (2) what is the range of the organic nutrient and materials capital and rates of transport (how does the current budget relate to the known range of standing stocks, rates of metabolism, and transport for salmon)?, (3) how have humans altered nutrient budgets?, (4) what adaptive management actions might be warranted and feasible with respect to salmon and nutrient cycling to push terrestrial and aquatic systems toward desirable goals?, and (5) what are the desired future conditions?

The WSP explicitly recognizes the need to treat salmon and their habitats or ecosystems as integrated entities for assessment and management. However, it also acknowledges a limited ability to immediately incorporate a wide range of ecosystem values and principles into salmon management given the complexity of the types of questions posed above and a limited experience in designing, implementing, and supporting ecosystem based management (EBM) frameworks. Regardless, it is obvious that the breadth and complexity of issues that must be engaged to ensure prudent management for the long term sustainability of the salmon stock-and-habitat complex recommends much greater research and management efforts on this front.

The development of an effective EBM framework to ensure sustainability of the salmon-and-habitat complex over the expanse of geography as large as PNCIMA represents an enormous challenge. However, a considerable body of information and experience with developing EBM frameworks to facilitate natural resource and land use management in PNCIMA has already been developed by the government of BC, among others, through the activities of an independent Coast Information Team (CIT) to consider land and resource management planning (LRMP) in PNCIMA from an EBM perspective (BC Coast Information Team 2004). The CIT's task was to produce information to help governments and participants in land and resource planning processes reach decisions that achieved ecosystem based management. The efforts of the CIT were clearly not focused on the full range of salmon management issues (*e.g.,* those identified in this chapter or by the WSP) and consequently both the content and implementation of their EBM approach has been criticized (Paquet *et al.* 2004). Nonetheless, CIT activities have clarified many of the future requirements for EBM in PNCIMA and provide a foundation[1] that may be built upon to meet WSP objectives related to conservation, habitat protection, and ecosystem based management of Pacific salmon within PNCIMA.

7.0 GLOSSARY

Advection Zone – An area of horizontal, large scale movement of seawater.

Anadromous – Fish species that spawn (breed and lay eggs) in freshwater environments, but spend at least part of their adult life in a seawater environment.

Coastal Downwelling Domain (CDD) – One of three major fisheries production areas in the northeast Pacific Ocean (including: Coastal Upwelling Domain and the Central Sub-Arctic Domain; Ware and McFarlane 1989). The Coastal Downwelling Domain encompasses the coastal waters extending from Queen Charlotte Sound to the Aleutian Islands. The circulation pattern is dominated by the counter clockwise flowing Alaska Current.

Ecosystem based management – Ecosystem based management has been defined as "an adaptive approach to managing human activities that seeks to ensure the coexistence of healthy, fully functioning ecosystems and human communities. The intent is to maintain those spatial and temporal characteristics of ecosystems such that component species and ecological processes can be sustained, and human well-being supported and improved." (Excerpted from the CCLCRMP Framework Agreement/Draft Interim Plan, Coast Information Team Document called Ecosystem based Management Framework, April 2004).

Epibenthic – Refers to the area on the top of the sea floor. Epibenthic organisms may be freely moving or sessile (permanently attached to a surface).

Fidelity – "Homing fidelity" is the propensity for adult salmonids to return to their natal freshwater spawning grounds following maturation at sea.

Isobaths – A contour (or surface) of equal depth in a body of water.

Morphological – Refers to structure or form.

Pacific Decadal Oscillation (PDO) – A pattern of climate and ocean condition regimes occurring in the north Pacific Ocean (associated with the Aleutian low pressure system) that results in shifts in sea surface temperatures and plankton abundance on a decades-long time scale.

Paleoclimate – Climate for periods prior to the development of measuring instruments, including historic and geologic time, for which only proxy climate records are available.

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[1] For details readers may wish to consult the CIT EBM Planning Handbook, the Hydroriparian Planning Guide, the Scientific Basis of EBM, and the Policy and Institutional Analysis for more in-depth elaboration of the EBM Framework. All CIT documents are available for downloading from the CIT Web site at www.citbc.org

Paleoecological – The ecological interaction between ancient organisms and their environment.

Redd – A nest prepared by a female fish in the stream bed gravel, stones, or sand, where she deposits her eggs.

Riparian – A zone of transition from an aquatic to a terrestrial system, dependent upon surface or subsurface water. A riparian area may be located adjacent to a lake or estuary, as well as an ephemeral, intermittent, or perennial stream or creek.

Upwelling – A process in which cold, often nutrient-rich waters rise to the surface.

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