Trends in Abundance and Size of Coho Salmon in the Pacific Rim

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Abstract: In the early 1960s, average Pacific-wide landings of coho salmon reached a stable level of over 12 million fish that persisted for 3 decades, followed by a sharp decrease to under 6 million fish in 1997–2003 as a result of reduced marine survival and fishery restrictions in the Pacific Northwest and British Columbia. Spawning escapement increased in most streams after 1999 in response to restricted fishing and improved marine survival for some stocks. Marine survival has been spatially and temporally variable, accounting for an average of 54% (range 41–68%) of variation in wild adult returns to twelve systems from Washington to southeast Alaska. Average survival rates have been highest (> 12%) in southeast Alaska and Puget Sound, and lowest (4–6%) for the Washington coast, with British Columbia being intermediate (6–10%). Marine survival was highly variable over a limited spatial scale, indicating that localized marine environments are critically important to overall ocean survival. The average weight of coho salmon harvested in Alaskan fisheries has changed little since the 1960s, but indicators of average weight in southern British Columbia to the Columbia River declined from the 1950s to early 1990s, followed by a rapid rebound from 1993 through 2004.

Keywords: coho salmon, abundance, survival, escapement, size

INTRODUCTION

Spawning populations of coho salmon are currently distributed around the Pacific Rim from Monterey Bay in central California to the Russian Far East (Sandercock 1991). The species' protracted stream residence makes it sensitive to changes in its freshwater habitat. Human development has reduced the productive capacity of many watersheds from California to southern British Columbia (Beechie et al. 1994; Brown et al. 1994; Weitkamp et al. 1995; Bradford and Irvine 2000). However, widespread development of hatchery production during the 1970s and 1980s acted to offset reductions in natural stocks (Mahnken et al. 1998).

Compounding the effect of long-term changes in habitat productivity have been large variations in survival of smolts entering the ocean (Coronado and Hilborn 1998; Beamish et al. 2000). During the 1990s, very poor ocean survival helped drive natural stocks to low levels that threatened the continued existence of some populations, and stocks in several areas of the Pacific Northwest and Canada were listed as threatened or endangered (Good et al. 2005). Fisheries were curtailed in response to these declines and listings (Chen and Holtby 2002), and harvest-based measures of the species' status are no longer informative for southeastern portions of its range. At the same time, assessments based on catch for regions west of southeast Alaska have indicated a trend of strong returns to Alaska since the early 1980s and a decline in the Russian Far East since the early 1990s (Radchenko 1998; Geiger et al. 2002; Eggers et al. 2005).

Detailed stock information has played an increasing role in stock assessments from southeast Alaska to California (Brown et al. 1994; Weitkamp et al. 1995; Henderson and Graham 1998; Kope and Wainwright 1998; Anonymous 2002a; Shaul et al. 2004). Several intensively monitored populations, or indicator systems, in southeast Alaska, British Columbia and Washington provide detailed information on escapement, smolt production, marine survival, return abundance, exploitation rates and return/spawner. Populations that have been monitored for a decade or more are useful indicators for both fishery management and environmental change. In areas such as the Oregon coast, where fishing on wild stocks has been curtailed and where no indicator stocks exist, assessment of the recent abundance of natural stocks depends primarily on estimates of spawning escape-

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ment (Anonymous 2005). However, escapement information is very limited to non-existent in Alaska and the Russian Far East because of the logistical difficulty of measuring the number of spawners during wet fall months in widely scattered, remote systems. Given these considerations, an assessment of coho salmon abundance across the North Pacific Rim depends upon different types of information for different regions.

COMMERCIAL CATCH TRENDS

The total Pacific commercial catch increased gradually from the mid-1920s and reached a plateau in the early 1960s, averaging 12.5 million fish from 1962 to 1994 based on data reported by Eggers et al. (2005) and shown in Fig. 1. From the mid-1950s to late 1970s, the Japanese high seas catch averaged over 3 million fish annually, representing a quarter of the total Pacific catch. The inshore harvest increased near the end of the high seas fishery, averaging 11.4 million fish from 1979 to 1994 and peaking at 16.0 million fish in 1986 before declining precipitously to a record low harvest of only 4.5 million fish in 1997. Following 1997, the total harvest increased gradually to 7.1 million fish in 2004. The decline in harvest in the mid-1990s was attributed primarily to severe fishing restrictions in Washington, Oregon and California beginning in 1992 and in British Columbia beginning in 1996–1998. Meanwhile the average harvest in southeast Alaska increased slightly from 2.6 million fish in 1980–1996 to 2.8 million fish in 1997–2004 (Fig. 1). Alaska accounted for an average of 77% of the total Pacific coho salmon harvest during 1997–2004, compared with only 15% during a period of low Alaskan production in 1955–1977.

Commercial harvests in the Pacific Northwest (California, Washington, and Oregon) were at first steady and then increased slowly from 1925 until the 1970s, reaching peaks of over 4 million fish per year in 1971, 1974 and 1976 (Fig. 2). The harvests in that region remained strong until the early 1990s, but plummeted after 1991 due to poor returns and restricted fisheries (Weitkamp et al. 1995). Commercial harvests in southern British Columbia followed a similar trend but were not curtailed until the mid-1990s in response to the deteriorating status of local stocks including those of the Thompson River, a Fraser River tributary (Bradford and Irvine 2000). The steadily increasing harvests in southern British Columbia through the 1980s resulted from a combination of stable fishing opportunities and increasing hatchery releases that peaked in the mid-1980s (Mahnken et al. 1998).

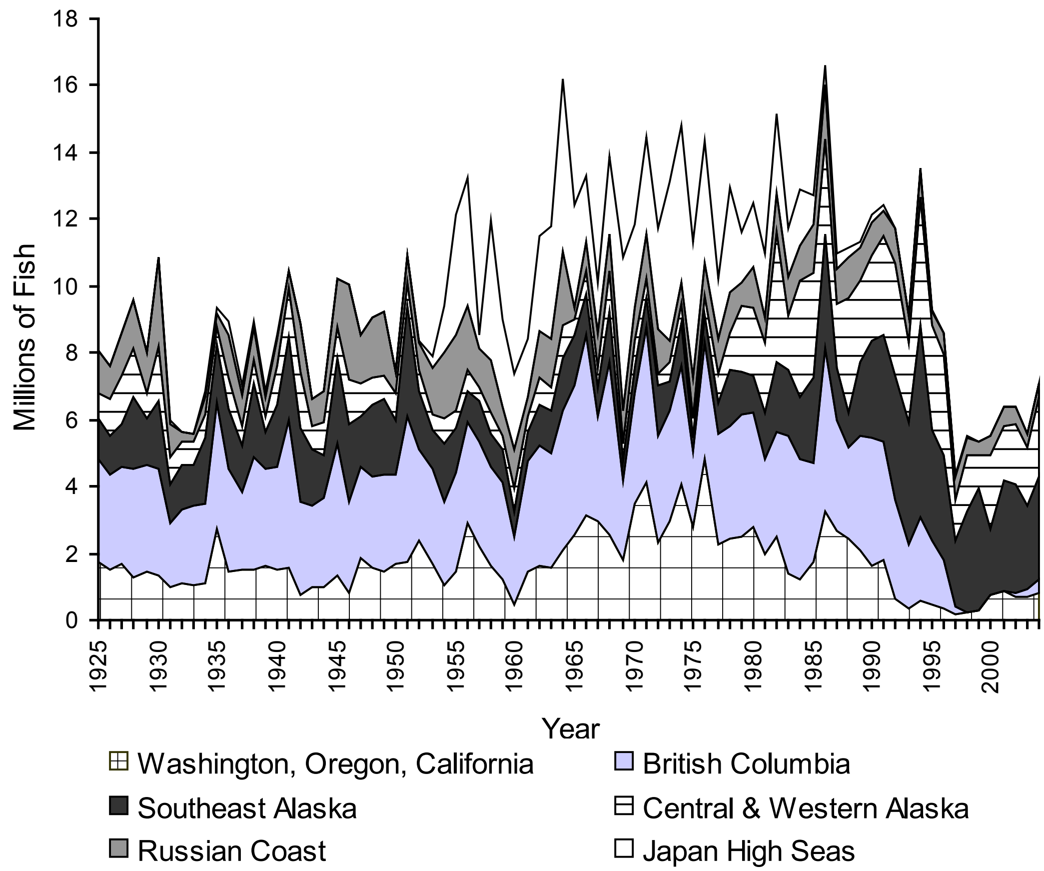

Fig. 1. Total commercial landings of coho salmon in the Pacific Rim, 1925–2004.

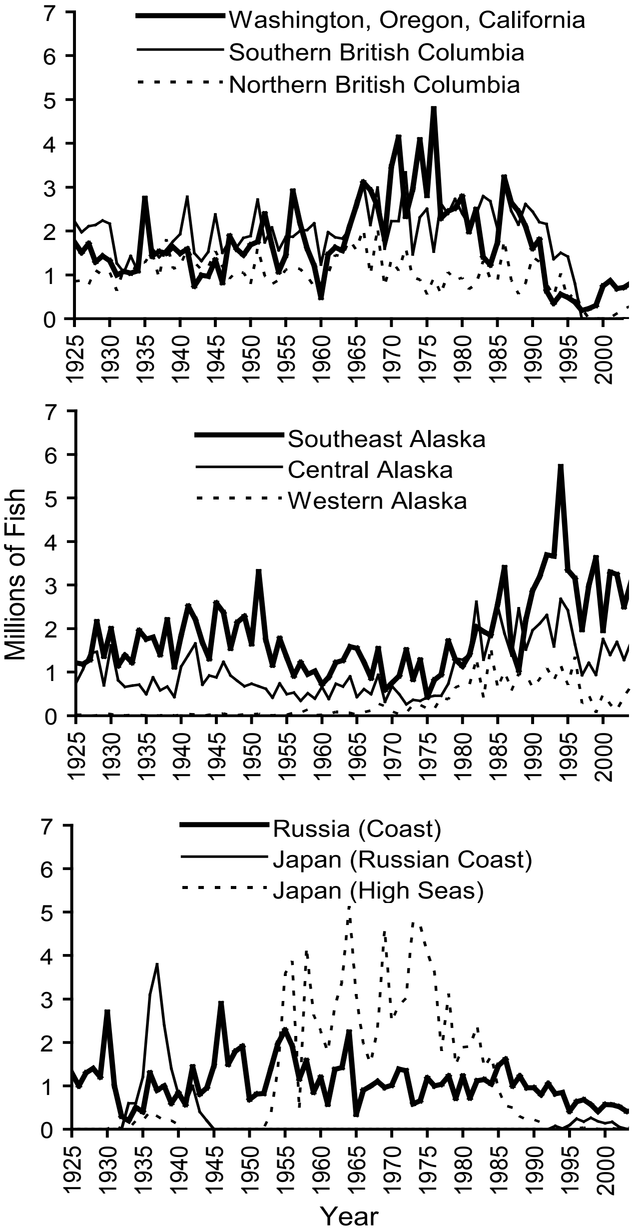

Fig. 2. Commercial harvest of coho salmon by region, 1925–2004.

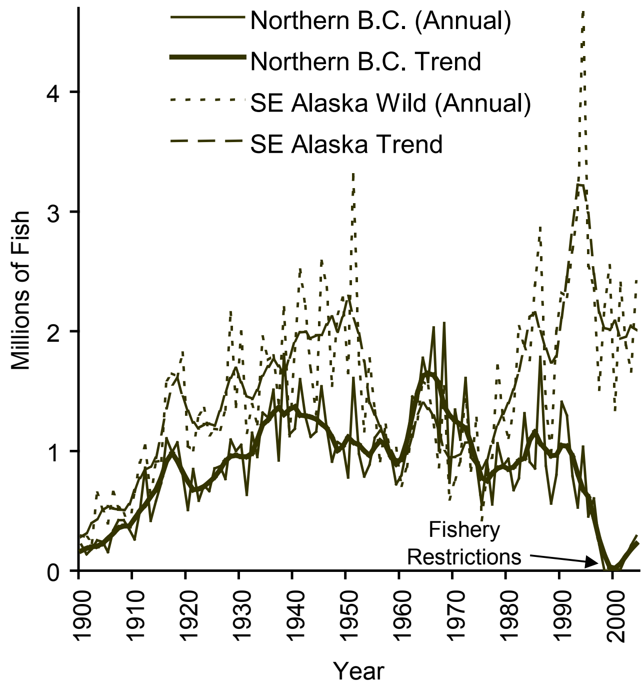

Fig. 3. Commercial catch of wild coho salmon in southeast Alaska and all coho salmon (including a very small hatchery component) in northern British Columbia, 1900–2004.

The harvest in northern British Columbia, comprised mostly of local wild stocks, followed a stable trend from the mid-1920s until the mid-1990s. Fisheries in that region were severely restricted after the extremely poor 1997 run that produced the lowest harvest since 1905. In contrast, the southeast Alaska catch declined sharply in the early 1950s and remained depressed through the late 1970s, but rebounded beginning in 1982. A significant factor in the recent increase has been hatchery production that developed rapidly in the 1980s and stabilized after 1990 at about 20% of the total commercial harvest (Shaul et al. 2004). Relatively stable fisheries on wild, locally produced stocks in northern British Columbia and southeast Alaska display a synchronous temporal pattern interrupted by major shifts in scale spanning a five-fold range of catch multipliers between the regions (Fig. 3). These shifts in 1954–1955, 1976–1977 and 1991–1992 are delineated by best-fit linear regressions as found in Fig. 4.

The second major shift occurred closely coincident with the well-documented 1977 regime shift (Beamish and Bouillon 1993; Francis and Hare 1994; Hare and Mantua 2000). However, there was an equally pronounced shift in the early 1990s preceding a period of very poor harvests in northern British Columbia compared with southeast Alaska in 1992–1997. Harvests in central Alaska fisheries from Prince William Sound to the Alaska Peninsula showed a similar increase to harvests in southeast Alaska after 1977, but have declined since 1997, while southeast Alaska harvests have remained high (Fig. 2). Development of commercial fisheries for coho salmon on many western Alaska systems draining into the Bering Sea did not occur until the late 1960s and 1970s. Harvests in the area were typically high during 1982–1996, but declined sharply in the late 1990s with poor returns to some systems. Low salmon prices in recent years have also constrained exploitation of many central and western Alaska stocks, particularly in more remote areas.

Russian coastal harvests of mostly wild coho salmon followed a very stable long-term trend from 1925 through 1992, around an average harvest of 1.15 million fish (Fig. 2). After 1992, however, harvests declined and averaged only 0.50 million fish in 2000–2004. Radchenko (1998) attributed the likely cause to an increase in illegal fishing on

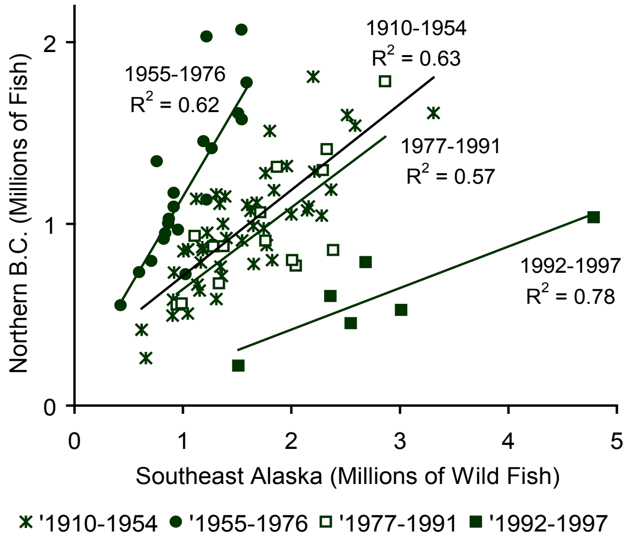

Fig. 4. Linear relationship between the commercial catch of wild coho salmon in southeast Alaska and all coho salmon in northern British Columbia apportioned into periods with best statistical fit, 1910–1997.

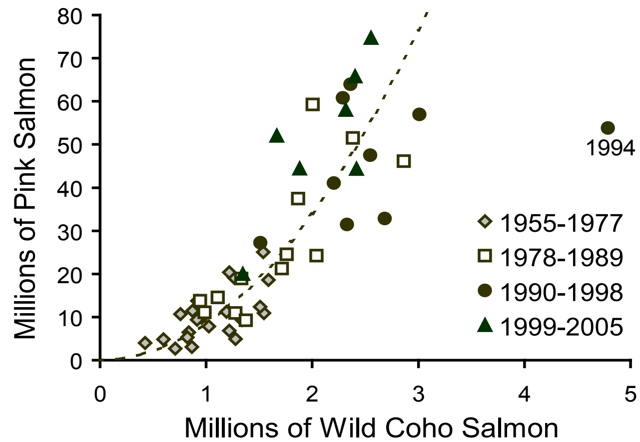

Fig. 5. Commercial catch of wild coho salmon compared with pink salmon in southeast Alaska, 1955–2005. The time series is divided into four periods that correspond with smolts entering the sea during recognized regime periods (< 1977, 1977–1988, 1989–1997 and 1998–2004).

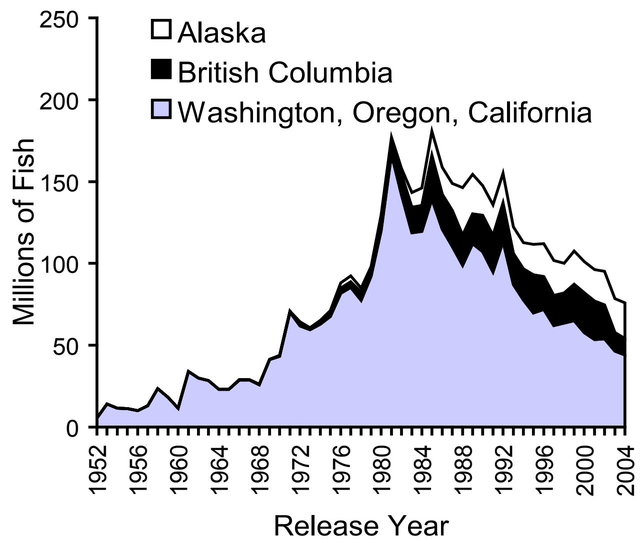

Fig. 6. Number of coho salmon released from Alaska, British Columbia and Pacific Northwest hatcheries, 1952–2004.

the spawning grounds. Small Japanese harvests along the Russian coast have averaged 0.12 million fish since 1993 but have not substantially offset the decline in the Russian harvest.

An informative comparison can be made between species within southeast Alaska. Coho and pink salmon are naturally abundant in streams throughout the region and both species spend slightly over a year at sea, so their returns reflect a similar experience in the ocean. Despite being exploited primarily in independent fisheries involving different gear, the relationship between the two species in the commercial harvest has been relatively consistent for over 50 years (Fig. 5), with the only substantial outlying observation being the record 1994 wild coho salmon harvest that corresponded with a large, but not exceptional, pink salmon harvest. A substantial upward shift in abundance became evident after 1981 and catches remained very high on average following the 1989 regime shift (Hare and Mantua 2000). However, there is no clear effect of a regime shift in 1998 (Peterson and Schwing 2003). Since 1990, low coho and pink salmon harvests approaching those during 1955–1977 have occurred only twice, in 1997 and 2000.

HATCHERY RELEASES

Hatchery production of coho salmon in western North America began around 1900 (Mahnken et al. 1998) but remained very limited until the 1950s and 1960s when advances in culture techniques led to improved post-release survival of hatchery fish (Lichatowich and McIntyre 1987). Hatchery releases in the Pacific Northwest and British Columbia of all life stages comprised primarily of smolts increased rapidly in the 1970s and peaked in the Pacific Northwest at 167 million fish in 1981 (Fig. 6) based on data reported by the Pacific States Marine Fisheries Commission. Alaskan production reached 1 million fish released in 1972 and increased until the late 1980s before stabilizing. The coast-wide peak of nearly 181 million fish was achieved in 1985 when Canadian hatcheries boosted smolt output to improve recreational fishing for the 1986 World Exposition in Vancouver. Coastwide releases remained relatively stable from 1987 to 1992 at 136–159 million fish, and then declined to 76 million in 2004. Releases from Oregon and Alaskan facilities have remained relatively stable since 1997 at about 8–10 million fish in Oregon and 18–22 million fish in Alaska. Meanwhile, Washington production declined from 95 million fish in 1992 to 44 million fish in 2002 followed by a marked drop to 37 million fish in 2003 and only 34 million fish in 2004. British Columbia releases remained stable at 18–24 million fish from 1986–2002 but also declined markedly in 2003 and 2004.

TOTAL ABUNDANCE ESTIMATES

Direct estimates of the total number of returning adults are available for only a few systems in most regions. However, working estimates of total abundance of wild and hatchery fish are available for some geographic areas including Puget Sound, the Washington coast and a grouping of hatchery and wild catches and escapements known as the Oregon Production Index (Anonymous 2005). Run size estimates are shown as a proportion of the 1993–2003 average in order to compare temporal patterns among systems with widely varying production capabilities (Fig. 7).

The Oregon Production Index peaked in the early to mid-1970s at an average of nearly 3 million returning adults before declining to a lower but relatively stable average of about 1.6 million fish in 1977–1991. In the early 1990s, the index declined even more dramatically to an average of only 323,000 fish in 1993–1999 before rebounding to an average of about 1.1 million fish in 2000–2004.

Combined wild and hatchery returns to Puget Sound (excluding ocean harvest) peaked during 1986–1988 but trended downward in the 1990s to a record low return in 1999, followed by improved returns in 2000–2003 (P. Lawson, NMFS, NW Fish. Sci. Center, 2032 SE O.S.U. Dr., Newport, OR, 97365-5275, pers. comm.). The total wild return to the Queets River on the Washington coast followed a pattern similar to that of Puget Sound, with a trend toward poor returns during 1992–1999 followed by a rebound (S. Wang, Quinault Nation, 3010 77th S.E., Suite 104, Mercer Is., WA 98040, pers. comm.). The Queets River return was exceptionally poor in 1994 and 1997 at about 2,000 fish each year but reached a peak of nearly 29,000 fish in 2001.

Wild coho salmon returns to Black Creek and Salmon River in Georgia Strait declined after 1991 and remained depressed through 2004. The Salmon River stock declined the most due to a decrease in smolt production as well as survival. Returns to Carnation Creek on the west coast of Vancouver Island declined proportionately less overall, but became highly variable during 1994–2000 with extremely low returns in 1994, 1997 and 1999.

Returns to northern British Columbia indicator systems followed relatively stable trends since the late 1980s but were very weak in 1997. Two of the northern British Columbia indicators, Lachmach River and Zolzap Creek, are located in the vicinity of the Nass River near the boundary with southeast Alaska and their pattern of abundance exhibits some features similar to nearby southeast Alaska

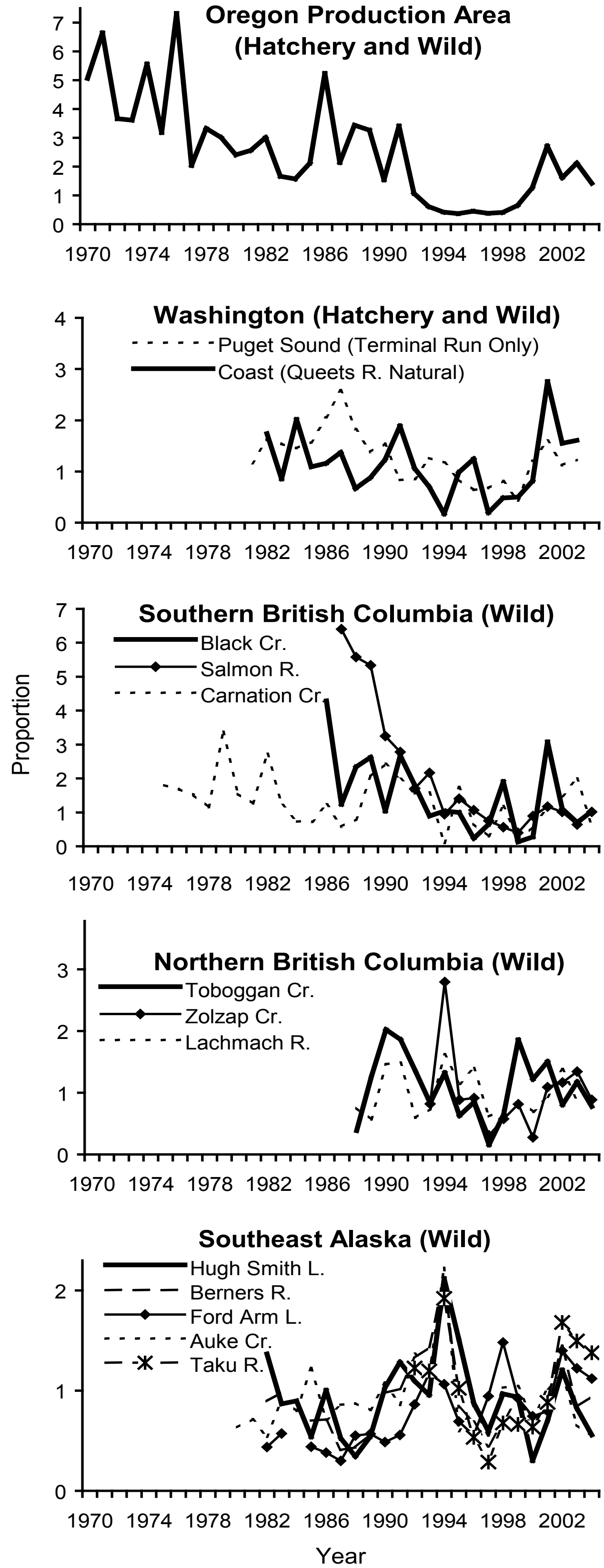

Fig. 7. Indicators of the total abundance of coho salmon returns from Oregon to southeast Alaska as a proportion of the 1993–2003 average.

stocks (Fig. 7). The return to Toboggan Creek, located further south in the upper Skeena drainage, may be more indicative of the recent abundance pattern reflected in the region's commercial catch (Fig. 3). The temporal pattern of Toboggan Creek returns compared with southeast Alaska stocks suggests that the period of highly divergent abundance indicated by commercial catch in 1992–1997 (Figs. 3 and 4) continued through 1998 before shifting again to a period of more balanced abundance between the regions.

Wild returns to most southeast Alaska systems have been relatively stable since the early 1980s, with the exception of very strong returns to inside systems in 1994 and a steadily increasing trend in returns to Ford Arm Lake, on the outer coast. Returns to the southeast Alaska indicator systems were weak on average in 2000, uniformly strong in 2002, and mixed in 2004.

ESCAPEMENT

Data series of comparable escapement estimates are very limited, particularly in more remote areas, because of the species' broad spatial distribution and tendency to spawn in coastal streams during periods of high precipitation. We examined established escapement indicators for the Oregon and Washington coasts and Puget Sound (Anonymous 2005) but restricted our review in more northern areas to limited data subsets, including only the highest quality and most comparable estimates.

Most indicators of natural coho salmon escapement from the Oregon coast to Alaska increased in 2000–2004 to levels above the averages for the 1980s and 1990s (Fig. 8). However, escapements were lower in 2004 compared with 2001–2003 in most monitored systems. In areas south of Alaska, the recent increase appears to have resulted from greatly restricted fishing combined with improved marine survival in some areas. During 2001–2004, natural stock escapements on the Oregon coast ranged from 3–5 times the 1970–1999 average.

Indicators of natural escapement also reached recent peak levels during 2000–2004 on the Washington coast, in Puget Sound and in some systems in British Columbia and Alaska. However, longer-term aggregate estimates of escapement reviewed by other authors indicate that escapements in British Columbia and the Pacific Northwest had likely decreased substantially before more detailed stock monitoring was initiated. Henderson and Graham (1998) presented information indicating that aggregate spawning escapement in British Columbia declined by over 70% from the 1950s and early 1960s to the mid-1990s.

In southeast Alaska, very little effort was made to index coho salmon escapements prior to the 1980s. Marine survival rates and fishing opportunity have remained more constant in that region. However, low fish prices during 2001–2003 led to lower exploitation rates and higher escapements for most indicator systems (Shaul et al. 2004).

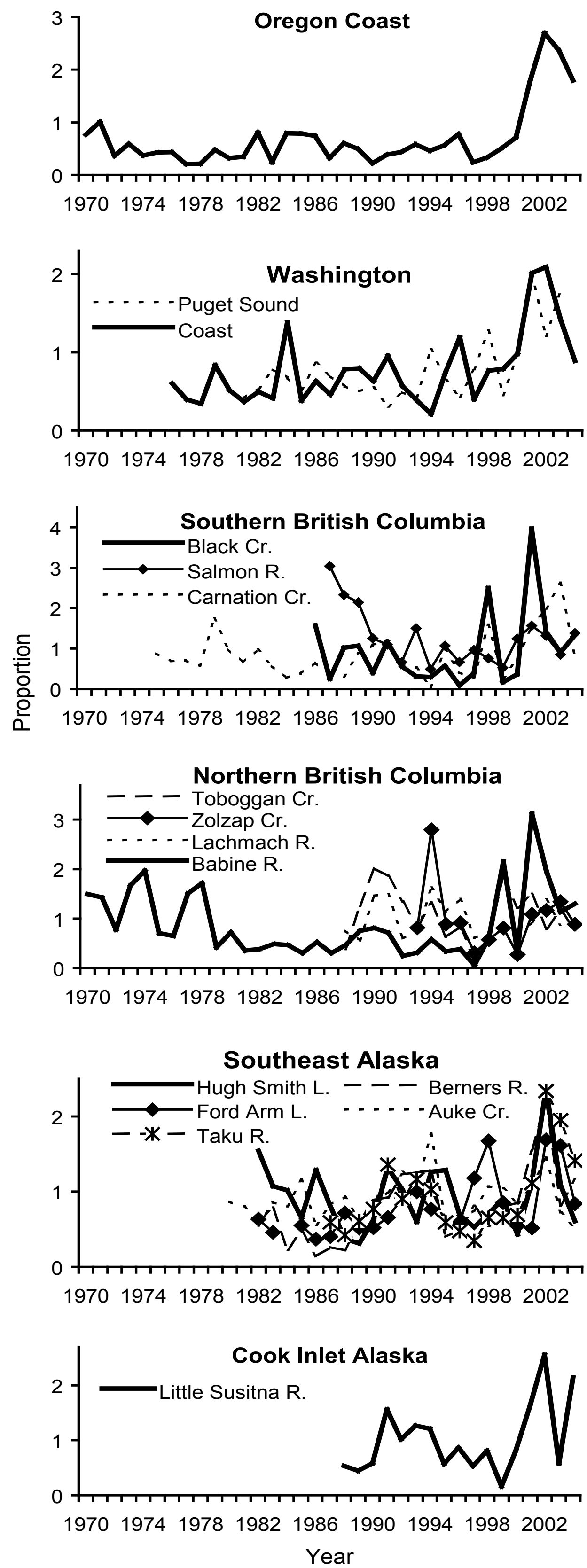

Fig. 8. Coho salmon wild indicator escapements from the Oregon coast to Cook Inlet, Alaska as a proportion of the 1993–2003 average.

MARINE SURVIVAL

Although harvest data is the only source of information indicating long-term abundance trends for most regions prior to 1975, marine survival rates provide insight into population trends and their causes during the past 20–30 years (Fig. 9). Most indicator stock projects were initiated following the 1977 regime shift, but are useful for evaluating later changes in marine survival. Hatcheries provide proxy indicators in many areas for which there are no wild stock estimates.

The number of returning adult salmon is a product of the number of smolts that migrate to sea and the proportion of those that return from the ocean to contribute to coastal fisheries and spawning escapements. A comparison of variability (coefficient of variation squared) in the number of smolts produced and their survival rate for twelve wild stocks from southeast Alaska to the Washington coast (Table 1) shows that marine survival was slightly more important on average (54%) in determining adult abundance, compared with freshwater factors including spawning escapement (46%). Spatially, the relative importance of marine survival was similar among four of the areas from southeast Alaska to Puget Sound, with its contribution to variation in adult returns being greatest for Washington coast stocks, including the Queets River (58%) and Bingham Creek (68%). However, both smolt production and marine survival were most variable, on average, for Washington and southern British Columbia stocks and least variable in southeast Alaska, with northern British Columbia being intermediate.

Marine survival varied substantially among geographical areas with wild indicator stocks in southeast Alaska and Puget Sound experiencing the highest average rates (12% or higher) and the Washington coast stocks experiencing the lowest average rates (4–6%).

Survival of smolts from inside indicator stocks in southeast Alaska peaked in the early 1990s (Fig. 9). Survival of smolts from Auke Creek in the northern part of the region increased from 9–11% in 1980–1982 to 14–25% during 1983–1989 and maintained a high average of 23% during 1990–2004. Survival rates for smolts from the Berners River in northern southeast Alaska and Hugh Smith Lake in southern southeast Alaska averaged 18% and 14%, respectively, during 1990–2004. Survival of smolts from these inside indicator stocks shows a consistent pattern over time that differs in some respects from the outer coastal stock, Ford Arm Lake. Shaul and Van Alen (2001) noted an apparent inverse relationship between average smolt production and average marine survival during 1993–1998 within two groups of closely situated systems; the first in northern southeast Alaska (Taku River, Berners River, Auke Creek) and the second in northern British Columbia and southern southeast Alaska (Nass River, Skeena River, Lachmach River, Hugh Smith Lake).

Survival rates averaged lower for wild indicator stocks in northern British Columbia, with estimates since 1990 averaging 11% for the Lachmach River and 6% for Zolzap

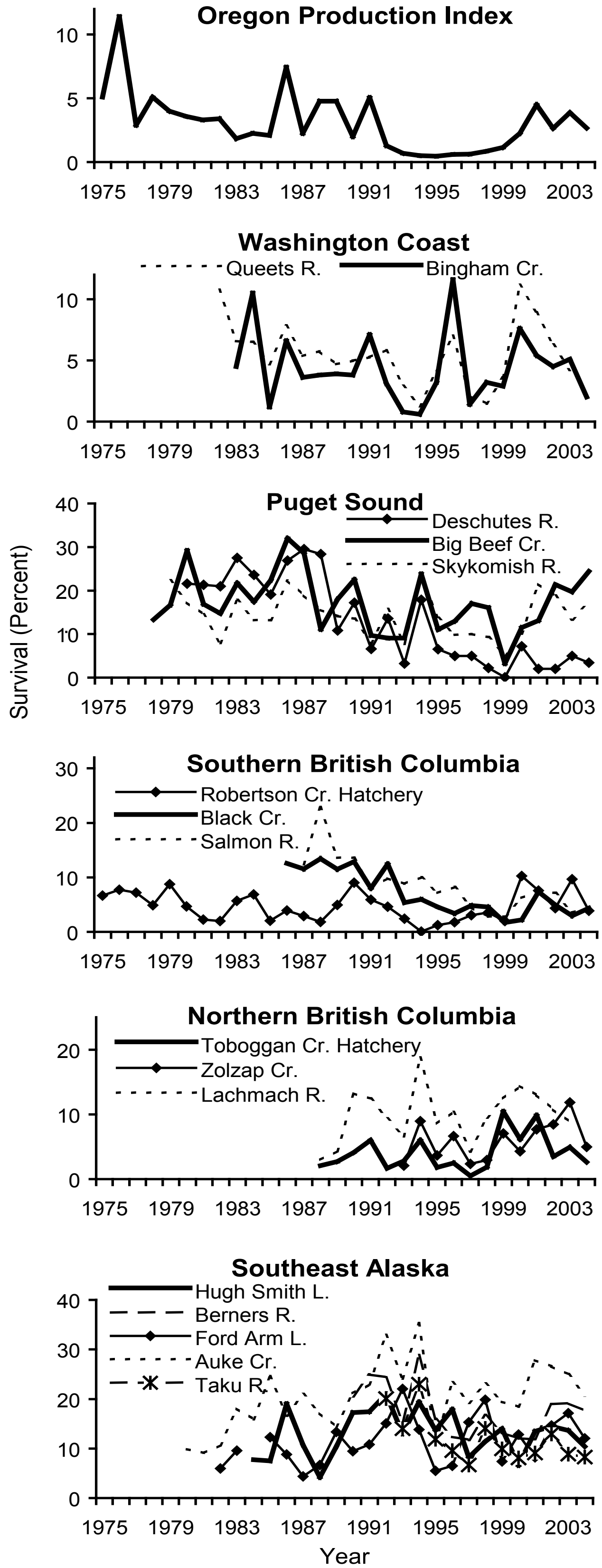

Fig. 9. Marine survival rate estimates for hatchery coho salmon smolts in the Oregon Production Index and for wild indicator stocks from Washington to southeast Alaska by adult return year.

Table 1. Average smolt production and marine survival estimates for twelve wild coho salmon stocks from southeast Alaska to the Washington coast with estimates of the percent of variation (CV^2) in total run size attributed to smolt abundance compared with marine survival.

Region	System	Return years	Average no. of smolts	Average survival (%)	Coeff. of variation		Percent of variation	
					Smolts	Survival	Smolts	Survival
Southeast Alaska	Auke Cr.	1980–2004	6,369	20.3	0.26	0.33	39	61
	Berners R.	1990–2004	201,857	17.6	0.29	0.30	47	53
	Hugh Smith L.	1984–2004	31,160	12.9	0.30	0.36	42	58
	Taku R.	1992–2004	1,592,808	12.0	0.46	0.40	56	44
N. British Columbia	Lachmach R.	1988–2003	31,324	10.0	0.43	0.42	52	48
	Zolzap Cr. [1]	1993–2004	63,201	5.9	0.53	0.51	51	49
S. British Columbia	Black Cr.	1986–2004	60,770	7.1	0.58	0.57	51	49
	Salmon R.	1987–2004	125,694	8.5	0.48	0.58	41	59
Puget Sound	Big Beef Cr. [2]	1979–2003	25,165	17.2	0.38	0.40	47	53
	Deschutes R. [2]	1980–2004	54,632	13.1	0.76	0.76	50	50
Washington Coast	Queets R. [3]	1982–2003	222,637	5.5	0.41	0.47	42	58
	Bingham Cr. [2]	1983–2004	32,053	4.4	0.45	0.66	32	68
				Average	0.44	0.48	46	54

[1] Bruce Baxter, LGL Ltd., 9768 2nd St., Sidney, BC, Canada V8L 3Y8, personal communication.
[2] Greg Volkhardt, Wash. Dept. of Fish and Wildlife, Science Div., Olympia, WA 98501, personal communication.
[3] Shizhen Wang, Quinault Nation, 3010 77th S.E., Suite 104, Mercer Is., WA 98040, personal communication.

Creek (B. Baxter, LGL Ltd, 9768 2nd St., Sidney, BC, Canada V8L 3Y8, pers. comm.). Survival rates for these stocks showed substantial fluctuation but no clear trend during this period. Both systems are in the far northern portion of the British Columbia coast and may not be reflective of marine survival further south from the Skeena River to Cape Caution, or in the Queen Charlotte Islands. Survival rates for smolts released from the Toboggan Creek Hatchery in the upper Skeena River system averaged 4% for 1988–2004 returns, including a very low survival rate of 0.5% in 1997 that corresponded with a record low commercial harvest in northern British Columbia. Survival of Toboggan Creek smolts increased dramatically in 1999–2001 after a period of generally poor survival in 1992–1998.

Average survival rates for hatchery stocks in British Columbia declined substantially after the 1981 return and continued to decline after the mid-1980s (Coronado and Hilborn 1998). The decline in the latter period is evident in survival rates of wild indicator stocks in Georgia Strait, which decreased from an average of 10% for Black Creek and 12% for Salmon River in 1986–1994 to average rates of 4% and 5%, respectively, during 1995–2004. Marine survival of smolts from Robertson Creek Hatchery on the west coast of Vancouver Island has been highly variable in recent years, ranging from barely more than 0% (1994) to 10% (2000) with a long-term average of 5%. Robertson Creek survival rates averaged just over 7% during 2000–2004, similar to the earliest years on record (1975–1977).

Survival rates have been highly variable for Pacific Northwest stocks. Two of the long-term indicator stocks located in mid-Puget Sound, Big Beef Creek and Skykomish River, appeared less affected by ocean conditions that resulted in reduced survival of many other Pacific Northwest and southern British Columbia stocks during the mid-1990s. Survival rates during 1992–1999 averaged 13% for Big Beef Creek and 11% for the Skykomish River, down from 20% and 16%, respectively, in 1978–1989 (P. Lawson, NMFS, NW Fish. Sci. Center, 2032 SE O.S.U. Dr., Newport, OR 97365-5275, pers. comm.). Survival rates for those stocks were high at 24% in 1994, a year when survival rates for stocks on the outer coast from Oregon to southern British Columbia were at or near record lows. In contrast with the two mid-Puget Sound stocks that have rebounded, marine survival of smolts from the Deschutes River located in southern Puget Sound has trended lower since 1995 (Fig. 9).

Survival of Washington coast indicator stocks declined sharply from a relatively steady trend averaging 5–6% in

1982–1992 to very low marine survival rates of 1–3% in 1993–1994 for the Queets River on the Olympic Peninsula and under 1% for Bingham Creek in Grays Harbor. Survival of these stocks then increased to 7% and 12%, respectively, in 1996 before declining again to between 1% and 4% in 1998 and 1999.

Hatchery smolts in the Oregon Production Index (OPI) followed a similar survival pattern to Washington coast stocks during the 1990s, but with the notable absence of a rebound during 1995–1997. OPI survival rates declined sharply beginning in 1992 from a 1975–1991 average of about 4.2% and remained at rates of 0.5–1.3% during 1992–1999 before rebounding to an average rate of 3.2% during 2000–2004.

SIZE AT TIME OF RETURN

A number of authors have noted a decreasing trend in the size of adult coho salmon, particularly in the southeastern part of their range (Ricker and Wickett 1980; Ricker 1981, 1995; Bigler et al. 1996). Weitkamp et al. (1995) reported a significant negative slope in 20 out of 35 time series of average weight and length measurements in coho salmon from California to southern British Columbia. They reported that adult coho salmon in Puget Sound and the Strait of Georgia declined at a much faster rate than in other areas, with Puget Sound fish declining by about 50% from 1972 to 1993.

We examined the average weight of fish caught in the troll fishery off the west coast of Vancouver Island (WCVI) and in net fisheries of the lower Columbia River in Zones 1–5 (Anonymous 2002b; S. Engwall, Oregon Dept. of Fish and Wildlife, 17330 SE Evelyn St., Clackamas, OR 97015, pers. comm.). Both data sets show a linear decline from the 1950s through the early 1990s (Fig. 10). The average weight of Columbia River fish declined from 1957 to 1992 (slope = -0.035; $p < 0.001$). The trend then abruptly reversed, and average weight rebounded at a faster rate during 1993–2004 (slope = 0.082; $p < 0.001$). The mean-average weight of 4.13 kg in 2000–2004 was actually higher than the average of 4.00 kg in the first five years of the data series (1957–1961) and was 43% above the lowest five-year mean-average weight of 2.89 kg in 1989–1993.

Coho salmon size in southern British Columbia followed a similar pattern, based on the average weight of fish landed in the WCVI troll fishery in Area 23 in September and sampled in escapements of two Vancouver Island systems. The data series for the troll fishery adds an additional 20 years of average weights to comparable 1951–1975 figures reported by Ricker and Wickett (1980). The average weight of coho salmon landed in the WCVI troll fishery declined by about 60% from 1951–1992 (slope = -0.050; $p < 0.001$). The fishery was closed after 1995.

In order to evaluate more recent trends in average weight of coho salmon in southern British Columbia, we converted average fork length to round weight for spawners from two wild stocks in southern British Columbia using a conversion estimate developed by Gray et al. (1981). Note that this conversion imposes the assumption that body condition remains constant, so converted weights may be a less sensitive indicator than actual measured weight. Trends in mean-average weight (kg) converted from length for the two stocks, Carnation Creek and Black Creek (Fig. 10), show an increase during 1993–2004 (slope = 0.172; $p < 0.001$). The estimated mean-average weight of spawners in the two creeks increased by 57%, from 1.91 kg in 1989–1993 to 2.99

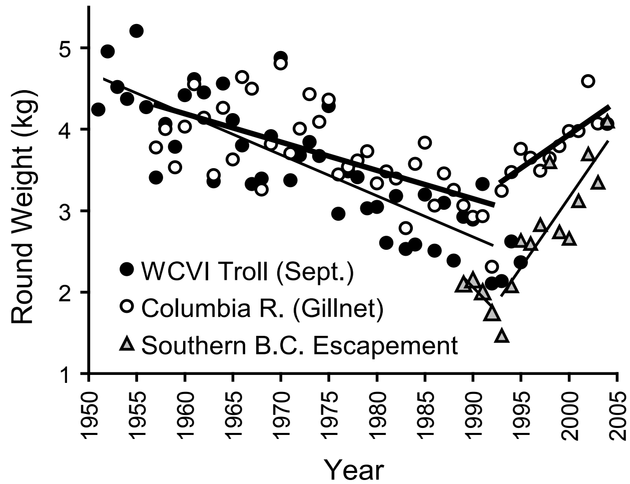

Fig. 10. Average round weight of coho salmon caught in the troll fishery on the west coast of Vancouver Island (WCVI) during September and the Columbia River gillnet fishery, and the mean-average weight of adult coho salmon in escapements to Black and Carnation creeks in southern British Columbia. Linear trends are shown for periods ending in 1992 and beginning in 1993.

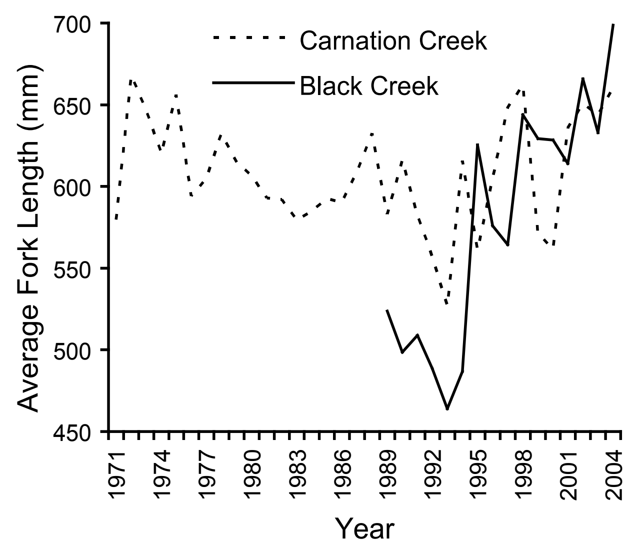

Fig. 11. Average mid-eye to fork length of age .1 wild adult coho salmon spawners in Carnation Creek on the outher coast of Vancouver Island and Black Creek on the east (Georgia Strait) side of Vancouver Island.

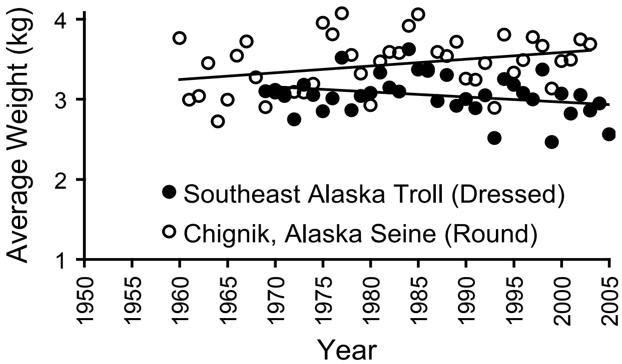

Fig. 12. Average weight of coho salmon caught in the southeast Alaska troll fishery (dressed weight) and in the Chignik purse seine fishery on the Alaska Peninsula (round weight).

kg in 2000–2004. The average length of spawners showed a far more marked increase since 1993 at Black Creek in the Strait of Georgia compared with Carnation Creek on the outer coast (Fig. 11) suggesting that the factors responsible for the decline in size were more influential in inside waters. Stocks in Georgia Strait and Puget Sound experienced the steepest decline in size prior to 1993 (Weitkamp et al. 1995).

It is unclear to what extent the decline and rebound in size of coho salmon in the Columbia River and southern British Columbia can be attributed to changes in fishing practices, changes in ocean productivity, density-dependent effects related to hatchery releases, or a combination of factors. Fisheries were conducted relatively consistently during the period of decline and were greatly curtailed in the early to mid-1990s, at about the time of the reversal. At least two broadly recognized ocean regime shifts occurred during the period and fish were large, on average, prior to 1978 when ocean conditions were most favorable for marine survival. However, size has rebounded to near pre-1978 levels, while recent hatchery smolt survival rates in the Oregon Production Index averaged only about half of survival rates prior to 1978. For both fisheries, we found weight to be negatively correlated with the number of fish released from hatcheries in the prior year. Average weight of Columbia River fish in 1960–2003 was negatively correlated with releases from facilities on the Columbia River and Oregon and Washington coasts (R^2 = 0.43; slope = -0.020; p < 0.001) while average weight in the WCVI troll fishery during 1960–1995 was negatively correlated with releases from facilities in southern British Columbia, Puget Sound and the Washington coast (R^2 = 0.59; slope = -0.022; p < 0.001). These relationships suggest that the increase and decline in hatchery production could have been an important factor contributing to trends in fish size.

In contrast to the Pacific Northwest and southern British Columbia, we detected very little change in the size of coho salmon landed in Alaskan fisheries, including two representative fisheries in the eastern and western Gulf of Alaska involving a single, relatively non-selective gear type (Fig. 12). There was no significant trend in average weight of coho salmon landed in the southeast Alaska troll fishery during 1969–2005 (slope = -0.004; p = 0.29) and a slight increasing trend in weight of fish landed in the Chignik purse seine fishery on the Alaska Peninsula during 1960–2003 (slope = 0.008; p = 0.03).

DISCUSSION

Although the overall Pacific Rim catch has remained near record low levels since the mid-1990s, other recent information on the status of wild stocks is more positive. Overall Alaskan production appears to have remained near the high levels experienced beginning in the early 1980s while spawning escapements have improved in most areas from British Columbia southward as a result of reduced fishing since the mid-1990s, combined with improved marine survival for some systems since 1999. A recent rebound in average adult weight in southern populations has alleviated concerns about the effect of decreasing size on spawning success (Weitkamp et al. 1995). Over the longer term, however, we anticipate that natural production of this species, particularly in the southern portions of its range, will continue to be challenged by freshwater environmental change brought about by increasing human development and climate change. Populations at lower latitudes will likely continue to experience greater variability in both smolt production and marine survival compared with southeast Alaska populations. Recent declines in hatchery production combined with environmental and management changes make it unlikely that the Pacific-wide commercial catch will rebound to levels in the mid-1960s to mid-1990s that routinely exceeded 10 million fish annually.

Smolt production and marine survival estimates from throughout the coast indicate that freshwater and marine environments have both had an important influence on adult coho salmon returns, with marine survival contributing slightly more on average to variability in abundance within the past 25 years. Within the marine survival component, major differences in the spatial and temporal pattern of survival indicate that conditions specific to very localized marine waters such as southern Puget Sound can have a critical influence on abundance. At the same time, consistent decadal-scale patterns exist among major geographical areas such as southeast Alaska and northern British Columbia, and with other species, including pink salmon.

Evident trends in the average size of coho salmon raise interesting questions that deserve further study. Why have Alaskan adults not declined in size in conjunction with a tremendous increase in the number of salmon returning to the state? Why did fish in more southern areas decrease in size for about three decades, followed by a rapid rebound since 1993?

Changes in exploitation by selective fishing gear, density dependence related to changing hatchery production, and shifts in ocean productivity have all been suggested as potential explanations for the decline in size in southern areas (Weitkamp et al. 1995). The rapid rebound in size suggests that selective harvest, to the extent that it may have been responsible, did not have a lasting genetic effect on fish size. Substantial differences between inside stocks and coastal stocks, and an inverse relationship between adult size and hatchery production, both point toward potential limitations in productivity in local marine waters. On the other hand, a similar size decline in other salmon species in the North Pacific (Bigler et al. 1996) and an apparent reversal in a declining trend in chum salmon size in Washington and southeast Alaska in the mid-1990s (Helle and Hoffman 1998) suggest that the factors responsible for recent trends in adult size in southern coho salmon stocks may also be linked to broad change across the North Pacific ecosystem.

In some respects, the coho salmon is a difficult species to assess for historical abundance. Catches are minimally informative through time over most of its range because of changes in habitat capacity, artificial culture, markets and fishing regulations, and reliable escapement information is limited or non-existent in some regions. On the other hand, the species is very conducive to informative high-resolution research on an individual population basis. Specific life-history aspects, including relatively stable size at sea-entry and a stable ocean age, make it a consistently useful indicator species for marine conditions affecting both survival and growth. Wild indicator stocks from southeast Alaska to Washington not only provide information on the relationship between spawning escapement and population abundance needed for informed fishery management (Bradford et al. 2000), they also provide critical support for the role of coho salmon as a valuable indicator species for environmental change in freshwater and ocean environments. Continuation of these programs is essential in order for the species to fill both important roles.

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