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Factors Influencing Ocean Catches of Salmon, *Oncorhynchus* spp., off Washington and Vancouver Island

R. A. Low, Jr. and S. B. Mathews

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U.S. DEPARTMENT OF COMMERCE
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R. A. LOW, JR.[2] and S. B. MATHEWS[3]

ABSTRACT

The relative influence of various factors on ocean fishing success was evaluated for pink, *Oncorhynchus gorbuscha*, chinook, *O. tshawytscha*, and coho, *O. kisutch*, salmon off Washington and Vancouver Island. In addition, an evaluation was made of the practicality of predictive models for ocean catch. For each species, predictive regression equations were developed and their reliability evaluated in terms of the average percentage error of predicted catches from actual catches.

Pink salmon catches were significantly correlated with indices of brood year abundance and the average individual weight of fish caught in terminal areas during the brood year. Average error of predicted catches ranged upward of $\pm 25\%$. Success for chinook salmon in year i was highly associated with Columbia River hatchery releases of fall brood year groups $i-3$ and $i-4$, Canadian purse seine catches of immature chinook salmon in Canadian area 20 during August of year $i-1$, and troll catch per effort during the fall of year $i-1$. Washington troll and sport catches of chinook salmon were also significantly correlated with the amount of nominal fishing effort. Coho salmon catches were significantly associated with level of fishing effort, indices of brood year abundance of Columbia River wild coho salmon, and Columbia River jack returns the preceding year. The average error of predicted annual troll coho salmon catches off the central Washington coast was $\pm 15\%$ for 1966-75.

INTRODUCTION

Pink, *Oncorhynchus gorbuscha*, chinook, *O. tshawytscha*, and coho, *O. kisutch*, salmon returning to Washington waters are subjected to intensive ocean fisheries off the west coast of Vancouver Island and Washington. In inside waters, the level of exploitation by commercial netters and recreational anglers is based on the remaining harvestable portion of the runs. One of the salmon management objectives of the Pacific Fishery Management Council is to provide all ocean and inside fisheries the continuing opportunity to harvest salmon. In order to achieve equitable allocation of fishing opportunities in addition to conservation of salmon resources, management agencies must understand the relative effects of various factors on ocean fishing success. Because terminal area allocations for several species are based in part on preseason estimates of ocean interceptions, reliable predictive models for ocean catch are also desirable. Previous studies of effects of diverse conditions on abundance of and/or fishing success for the species mentioned have been limited to analyses of one or a few categories of data for a particular stock in a limited area. Very few of these studies have addressed the ocean fisheries.

Trends in the Washington troll fishery through 1975 were described by Wright (1970, 1976). Haw et al. (1967) described the development of the Washington salmon sport fishery prior to 1965, while Phinney and Miller (1977) analyzed trends in the ocean sport fishery since 1970. United States Department of Commerce et al. (1977) provided a detailed account of the development and status of the ocean salmon fishery off California, Oregon, and Washington. Milne and Godfrey (1964) and Godfrey (1969, 1970) discussed aspects of the Canadian troll fishery off the west coast of Vancouver Island.

Although fisheries managers have traditionally assumed that abundance of pink salmon is associated with brood year abundance in a Ricker spawner-recruit curve, other associations have been reported. One factor that may influence the abundance of offspring is the average individual weight of spawning females, since higher fry survival rates appear to be associated with larger brood females (Skud 1973). Survival of out-migrant fry in estuarine assembly areas may also reflect a prey-predator relationship with yearling coho salmon (Hunter 1959). During their marine residence, pink salmon from the Fraser River system and Puget Sound tributaries appear to follow a similar migratory route (Neave et al. 1967; Royce et al. 1968). The oceanographic condition most likely to be associated with survival of juveniles and catchability of maturing fish is surface sea temperature (Vernon 1958; Favorite 1961; Birman 1964; International Pacific Salmon Fisheries Commission 1974). The average individual weight of maturing pink salmon varies inversely with run strength in inside waters (International Pacific Salmon Fisheries Commission 1974). Ocean catches could be related to all of these elements.

A Ricker-type spawner-recruit relationship has also been assumed for major chinook salmon stocks (Van Hyning 1973), but again other factors are involved. Contributing to production are hatchery releases, of massive proportions in recent years (Wahle et al. 1975). During out-migration, juvenile fall chinook salmon, particularly Columbia River fish, may be detrimentally influenced by warmer-than-normal surface coastal sea temperature (Vernon 1958; Van Hyning 1968) and lower-than-normal upwelling rates (Van Hyning 1968). The location and extent of upwelling may also affect catchability of maturing chinook salmon because of the influence on abundance and distribution of forage. Tully (1954) found that the only variables significantly associated with troll catch rates off the west coast of Vancouver Island were wind velocity and direction. Because

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summer upwelling there is a function of those elements (Hollister 1966), he may have indirectly detected an association between catchability and upwelling. Fall chinook salmon of several age groups comprise the bulk of the ocean catches, so fishing success late in the previous season may indicate abundance of some age groups in the following year. All of these factors could be related to ocean fishing success for chinook salmon.

For those coho salmon stocks where naturally produced fish are a major component, environmental factors have been found to strongly influence recruitment; while in most major production areas, massive hatchery releases have complicated stock-recruitment relationships in recent years. Low streamflow rates during the year of juvenile freshwater residence reduce survival (Neave 1949; Smoker 1953), and an index of summer flow rate in year $i-2$ is used to predict Puget Sound wild coho salmon runs in year i (Zillges 1974, 1977).

Environmental conditions during periods of preemergence and hatching could also influence abundance. The same oceanographic conditions suspected of influencing survival of juvenile chinook salmon and catchability of harvestable fish could also affect coho salmon. Hollister (1956) referred to a positive association between troll success off the west coast of Vancouver Island and surface salinity, Wright et al. (1976) found that peak success in the Oregon troll fishery coincided with surface sea temperatures of 11°-13°C, Gunsolus (1978) described a positive relationship between abundance of adult coho salmon off Oregon and spring upwelling in the previous year, and Fisheries of Canada (1971) cited an example of the influence of upwelling on trolling activities. Jack returns are considered indicative of survival of a particular year class and may be valid indicators of abundance of maturing Columbia River coho salmon (Gunsolus 1978). Growth rate may show a direct relationship with survival in the marine environment (Henry 1961). There may be an inverse relationship between average individual size and catchability, with smaller coho salmon staying closer to shore and being more vulnerable to the fisheries, an opinion corroborated by results of Oregon Department of Fish and Wildlife studies (Gunsolus 1978). All of these diverse elements could affect ocean fishing success for coho salmon.

In this paper, we have examined the relative influence of 1) brood year abundance, 2) hatchery releases, 3) freshwater environmental factors, 4) oceanographic conditions, and 5) levels of nominal effort on a) commercial ocean troll catch, b) troll catch per unit of effort (CPUE), and c) ocean sport catch of pink, chinook, and coho salmon during 1955-75 from Tillamook Head, Ore., to Cape Scott, Vancouver Island. Several predictive models for ocean catch based on the above factors were developed and their reliability evaluated.

METHODS

Catch and effort data for commercial fisheries were obtained from Washington Department of Fisheries (1955-75) and Canada Fisheries and Marine Service (1955-75a). Sources of sport fishery data were Haw and Buckley (1965), Nye and Ward (1966), Haw et al. (1967), Washington Department of Fisheries (1966-75), and Canada Fisheries and Marine Service (1955-75b). Hatchery production figures originated from Wahle et al. (1975) and unpublished data (Foster[4]) of the Washington Department of Fisheries, Hatchery Division. Estimates of run size and escapements were from Oregon Department of Fish and Wildlife and Washington Department of Fisheries (1976) for Columbia River stocks, International Pacific Salmon Fisheries Commission (1962, 1968, 1974, 1976) for pink salmon, and unpublished data (Zillges[5]) for Puget Sound chinook and coho salmon. Average winter air temperatures and river peak momentary discharge rates at Washington stations were obtained from U.S. Geological Survey records, Tacoma, Wash. Surface sea temperatures and salinities at Canadian shore stations were from Hollister and Sandnes (1972), Hollister (1972, 1974), and Giovando and Hollister (1974). Indices of upwelling were modified from Gunsolus (1978). Data obtained directly (or slightly modified) from readily available published sources are not reproduced here and can be found in Low (1979).

The Washington Department of Fisheries and Canada Fisheries and Marine Service used a marine statistical area system to report commercial catches in numbers of salmon by species and effort in either individual vessel landings (Washington) or days fished (Canada) during 1955 through 1975. We have pooled data for these areas according to the district classification shown in Figure 1. Washington data reported by geographical category were classified as follows: 1) Columbia River district: Tillamook Head to Cape Shoalwater; 2) Coastal Washington district: a) Cape Shoalwater to Cape Elizabeth, b) Cape Shoalwater to Cape Johnson, c) Cape Elizabeth to Cape Johnson, d) Split Rock (near Cape Elizabeth), e) Quillayute (zone 3), f) La Push; 3) Puget Sound district: a) Cape Flattery (zone 4), b) Barkley Sound (area 23), c) Swiftsure (area 21).

[4]R. Foster, Washington Department of Fisheries, Olympia, Wash., pers. commun. February 1976.

[5]G. Zillges, Washington Department of Fisheries, Olympia, Wash., pers. commun. October 1977.

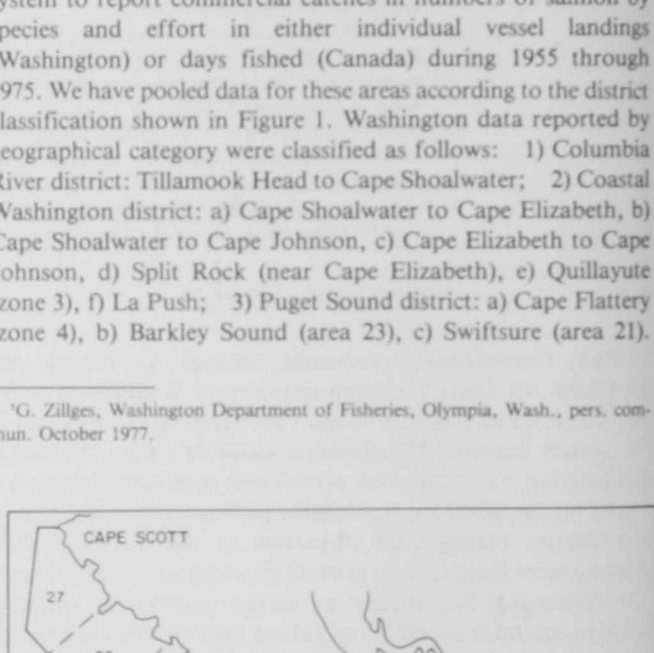

Figure 1.—Salmon statistical catch areas.

Canadian area C is arbitrarily included in the Puget Sound district on the assumption that most of the catches reported there were made north of La Push. Data reported for Washington fishermen north of Barkley Sound and for the following categories were not considered due to their geographic dispersal and relative insignificance: 1) Tillamook Head to Cape Elizabeth, 2) Tillamook Head to Barkley Sound, 3) Cape Elizabeth to Barkley Sound. These data were included when calculating statewide totals. Catches of pink salmon south of Cape Johnson were insignificant and were not included in the analyses. Because of the difficulty in standardizing effort for Washington and Canadian trollers, data for each group were analyzed separately. Sport catch was also analyzed separately and is referred to by port of origin (Ilwaco, Westport, La Push, Neah Bay).

Because the ocean hook-and-line fishery is noncompetitive according to Ricker's (1975) criteria, then theoretically CPUE is a more valid index of abundance than is catch; but, in practice, there are limitations to the use of sport CPUE and Washington troll CPUE for this purpose. A restrictive (three salmon per day) ocean bag limit for Washington fishermen was in force during the period considered and the number of salmon caught per angler trip has little quantitative meaning. The overall sport catch is a better index of salmon abundance in this application. Wright (1970) discussed the problems associated with the use of Washington troll CPUE as an index of ocean salmon abundance, most of which stem from the vague dimensions of the landing as a unit of effort. For the Washington troll fishery, effects of various factors on both catch and CPUE were examined. Trends in Canadian troll CPUE have closely paralleled those in troll catch, particularly for chinook and coho salmon. In trend analysis of the Canadian fishery, it therefore makes little difference whether catch or CPUE is the dependent variable.

The analytical procedure employed was linear regression, with 1) commercial ocean troll catch, 2) troll CPUE, or 3) ocean sport catch in particular areas during specified periods being the dependent variables. All regressions were calculated with BioMed computer program BMDO2R (Dixon 1968). When the regression equation included an index of brood year abundance as an independent variable, we used a log transformation based on Ricker's spawner-recruit relationship, i.e.,

$$\ln R = \ln a - bS \ldots + \ln S,$$

where R is troll catch, etc. in year i and S is the index of abundance in the brood year $i-x$, x being the age in years at maturity. Ricker (1975) discussed appropriate data transformations for exploratory correlations involving physical factors. In preliminary work, we found ranking to be the only useful alteration when dealing with environmental variables.

Pink Salmon

Indices of brood year abundance.—Several indices (Table 1) were based on net gear catch or CPUE for each of four major stocks: 1) the Washington run, 2) the Canadian non-Fraser run, 3) the early Fraser run, and 4) the late Fraser run. For each, we summed net gear catch and effort as indicated below, based on information in Hourston et al. (1965) and Ward (1958).

Washington run: 1) one-half of the net catch (or effort) in Canadian area 20 during 15 July through 15 August; 2) one-half of the United States and Canadian net catch (or effort) in the Strait of Juan de Fuca during 15 July through 15 August; 3) annual trap, drag seine, and set net catch (or effort) in Puget Sound; 4) annual net catch (or effort) reported for Admiralty Inlet, West Beach, Skagit Bay, Port Susan, Port Gardner, and Bellingham Bay, exclusive of that in the previous category.

Canadian non-Fraser run: 1) and 2) as above; 3) net catch (or effort) at Point Roberts, Rosario, Salmon Banks, and San Juan Islands during 1 August through 15 August.

Early Fraser run: 1) Canadian net catch (or effort) in Canadian area 20 during 16 August through 31 August; 2) United States and Canadian net catch (or effort) in the Strait of Juan de Fuca during 16 August through 31 August; 3) net catch (or effort) at Discovery Bay, the San Juan Islands, Rosario, and the Salmon Banks during 16 August through 6 September; 4) net catch (or effort) at Point Roberts during 16 August through 9 September; 5) net catch (or effort) in the Fraser River during 1 September through 20 September.

Late Fraser run: 1) Canadian net catch (or effort) in Canadian area 20 during September; 2) United States and Canadian net catch (or effort) in the Strait of Juan de Fuca during September; 3) net catch (or effort) at Discovery Bay, the San Juan Islands, Rosario, and the Salmon Banks during 7 September through 15 October; 4) net catch (or effort) at Point Roberts during 10 September through 15 October; 5) net catch (or effort) in the Fraser River during 21 September through 20 October.

To calculate CPUE for net gear, we standardized effort in Washington gill net landings. Within an area, CPUE for each gear type was calculated as $\frac{\Sigma C}{\Sigma f}$ where C was catch in fish and f was effort in landings. Then an efficiency factor E of 1.00 was assigned to gill nets. Efficiency factors for other gears (1, 2 . . .) were calculated as $E = N(\frac{1}{G})$, where N was CPUE for a gear type and G was CPUE for gill nets. Then the total standardized effort f_{std} for a particular year in a specific area was calculated as:

$$f_{std} = f_{gill\ net} + E_1 f_1 + E_2 f_2 \ldots .$$

We calculated catch per standardized unit of effort as the total catch for all net gears divided by the total standardized effort. Efficiency factors are shown below. If CPUE for gill nets and another gear was not significantly different, catch and effort were added for both types.

Area	*Gear*	*E*
Puget Sound	Gill net and set net	1.00
	Drag seine	4.13
	Indian trap	16.29
	Purse seine	10.84
	Reef net	2.39
Area 20	Canadian gill net	1.29
	Canadian purse seine	23.89

Predator-Prey relationship.—If the following assumptions are met: 1) abundance of yearling coho salmon is proportional to the number of hatchery yearlings released that year and 2) increased numbers of yearling coho salmon contribute to reduced

Table 1.—Indices of brood year abundance of pink salmon based on net gear catch (in thousands of fish) and CPUE (in fish per standardized unit of effort).

Brood year	Washington run		Canadian non-Fraser run		Early Fraser run		Late Fraser run	
	Catch	CPUE	Catch	CPUE	Catch	CPUE	Catch	CPUE
1953	1,575.0	49.7	474.2	13.6	3,626.9	53.5	2,553.3	50.1
1955	804.7	21.1	272.0	6.8	5,185.6	48.6	3,445.6	39.3
1957	543.3	21.4	211.6	9.3	3,826.4	44.1	888.9	20.9
1959	320.4	16.4	169.3	7.0	2,611.3	42.5	1,221.0	21.8
1961	420.1	18.5	295.2	7.4	308.3	18.3	56.3	3.3
1963	3,983.6	79.8	793.0	22.0	3,097.1	69.1	1,442.5	34.0
1965	260.9	13.1	101.6	6.3	497.5	20.2	263.2	10.0
1967	199.2	6.3	179.5	6.9	4,520.8	62.7	1,887.1	34.4
1969	54.3	3.6	69.8	2.6	721.1	36.4	706.9	20.1
1971	207.2	11.6	69.3	3.0	1,829.8	23.5	2,045.5	40.6
1973	257.2	11.2	108.9	4.2	2,403.7	39.4	1,123.6	22.0

numbers of pink salmon out-migrants, then there may be a negative relationship between ocean catches of pink salmon in year *i* and hatchery releases of coho salmon of brood year group $i-3$. This possibility was evaluated by calculating regressions of 1) commercial ocean troll catch, 2) troll CPUE, and 3) sport catch of pink salmon in year *i* against weight of coho salmon yearlings of brood year group $i-3$ released from Puget Sound hatcheries. Hatchery releases are listed in Wahle et al. (1975).

Surface sea temperature.—Regressions of 1) commercial ocean troll catch, 2) troll CPUE, and 3) annual total ocean and inside Washington sport catch against mean surface sea temperatures for stations and periods indicated below were calculated. Locations of shore stations were described by Hollister (1960).

Station	*Time period*
Departure Bay	April-August, year $i-1$
Amphitrite Point	August-October, year $i-1$
Kains Island	September-October, year $i-1$
Cape St. James	September-October, year $i-1$
Langara Island	October-November, year $i-1$
Ocean Station P	February-April, year *i*
Langara Island	May, year *i*
Cape St. James	May-June, year *i*
Kains Island	June-July, year *i*
Washington coast	May, year *i*

Data were obtained from sources listed earlier in this section. Data for ocean Station P and the Washington coast were compiled from numerous sources and are reproduced below.

	Station P (°C)			*Washington coast (°C)*
Year	*February*	*March*	*April*	*May*
1955	—	—	—	8.80
1957	5.57	5.94	6.31	10.20
1959	5.28	5.03	5.71	10.20
1961	4.94	4.78	5.17	10.98
1963	6.14	6.00	5.86	12.39
1965	4.65	—	5.78	—
1967	5.27	—	5.37	13.42
1969	—	—	—	—
1971	4.98	4.24	4.73	9.05
1973	5.31	—	5.70	9.94
1975	5.42	5.12	4.87	—

The assumption must be made that conditions monitored at these sites are reflective of those in areas inhabited by the fish. Dodimead et al. (1963) considered conditions at Station P representative of those closer to the coast. Oceanographic conditions at Langara Island and Cape St. James reflect those in exposed ocean regions; those at Kains Island and Amphitrite Point reflect the conditions in exposed coastal areas (Hollister 1956). Surface temperatures in Departure Bay probably typify those in sheltered inland waters. Robinson (1957) compared surface sea temperatures at Amphitrite Point, a station at lat. 49°N long. 148°W, and in the coastal region bounded by lat. 48°-49°N long. 129°-130°W. She concluded that shore station data were indicative of conditions in coastal waters.

Individual size.—We calculated regressions of 1) commercial ocean troll catch, 2) troll CPUE, and 3) sport catch against the average individual weight of pink salmon caught in terminal area net fisheries in year $i-2$. Data for Canadian area 20 were included because fish from all major stocks are included in the catches there. Average weight was estimated as the aggregate weight of the catch divided by the estimated number of fish caught. For each area, regressions of troll catch and CPUE in each month on the individual weight of fish caught during that month were calculated. Weight data are listed in Table 2 and were derived from catch statistics in sources listed previously in this section.

Chinook Salmon

Indices of brood year abundance.—Indices consisted of escapement estimates, net gear catch, and net gear CPUE during peak run periods. Indices based on catch and CPUE are listed in Table 3. Year $i-4$ was considered the brood year except for Columbia River fall chinook salmon, for which data for years $i-3$ and $i-4$ were combined. Periods for major runs were as follows:

Run	*Inclusive Dates*
Spring chinook salmon	
Columbia River	1 March-31 May
Puget Sound	1 March-30 June

Table 2.—Average weight (in kg) of pink salmon. Values are round weight for net-caught fish, dressed weight for troll-caught fish.

	Net-caught fish		
Year	Area[1] 20	Fraser River[2]	Wash. Terminal Areas[3]
1953	2.65	2.83	—
1955	2.86	2.92	2.58
1957	2.43	2.56	2.38
1959	2.39	2.49	2.35
1961	3.25	3.86	3.07
1963	2.30	2.46	2.27
1965	2.90	3.03	2.91
1967	2.39	2.50	2.32
1969	2.77	2.87	2.65
1971	2.34	2.36	2.35
1973	2.49	2.47	2.47

	Troll-caught fish					
	C. Elizabeth-C. Johnson			C. Flattery		
Year	June	July	August	June	July	August
1955	2.47	2.41	2.70	2.44	2.73	2.45
1957	1.56	1.81	2.00	1.69	1.90	2.05
1959	1.86	1.99	2.15	1.64	1.91	1.98
1961	2.59	2.39	2.71	2.30	2.63	2.75
1963	1.67	1.78	2.00	1.67	1.72	1.88
1965	2.10	2.37	2.53	2.13	2.55	2.54
1967	1.56	1.94	2.10	1.40	1.85	2.04
1969	1.85	2.12	2.18	2.00	2.39	2.39
1971	1.47	1.89	2.32	1.48	1.91	2.16
1973	1.62	2.10	2.28	1.69	2.09	2.38
1975	1.47	2.12	2.44	1.43	2.04	2.44
	Areas 21 and 23			Areas 25-27		
Year	June	July	August	June	July	August
1955	—	2.64	2.74	—	2.60	2.69
1957	1.97	2.30	2.04	1.90	1.95	2.25
1959	1.75	1.96	2.02	1.66	1.83	2.04
1961	2.41	2.60	2.58	2.53	2.75	2.78
1963	1.56	1.72	2.13	2.11	1.88	2.56
1965	2.09	2.71	2.59	1.88	2.72	2.54
1967	1.50	1.85	2.00	1.56	1.84	2.04
1969	1.68	2.17	2.46	1.83	2.18	2.39
1971	1.54	1.76	1.99	1.68	1.78	1.93
1973	1.66	1.83	1.97	1.54	1.58	1.86
1975	1.43	1.89	2.29	1.86	1.86	1.95

[1]August purse seine catch.
[2]September gill net catch.
[3]Annual net catch for P. Susan, P. Gardner, and Skagit Bay.

Point Roberts	1 March-30 June
Fraser River	1 March-end of 3d Canadian statistical week in July
Fall chinook salmon	
Columbia River above Bonneville Dam	1 August-31 August
Total Columbia River	1 August-31 December
Puget Sound	1 July-31 October
Point Roberts	1 July-31 October
Fraser River	Last Canadian statistical week in July through 31 October

Since many of the chinook salmon caught at Point Roberts were of Fraser River origin during the years considered, we combined catch and effort data for Point Roberts with those for the Fraser River. Effort was standardized as described for pink salmon, using efficiency factors listed below:

Table 3.—Indices of brood year abundance of chinook salmon based on net gear catch (in thousands of fish) and CPUE (in fish per standardized unit of effort).

	Columbia River catch		
Brood year	Springs	Early (Aug.) Falls	Late (Sept.-Dec.) Falls
1953	88.1	108.6	44.3
1954	89.8	85.4	39.7
1955	224.1	126.6	49.6
1956	164.0	162.2	14.2
1957	117.8	120.4	24.4
1958	126.8	78.9	65.0
1959	77.0	78.9	22.2
1960	64.8	128.7	8.1
1961	64.4	89.6	26.1
1962	112.4	127.2	31.7
1963	81.0	67.6	31.4
1964	67.2	107.3	47.2
1965	93.1	146.2	57.1
1966	40.6	112.4	33.8
1967	44.8	121.9	36.9
1968	29.1	50.6	99.0
1969	63.7	108.0	78.3
1970	45.4	149.6	102.8
1971	35.3	93.8	122.1
1972	112.7	96.3	43.4

	Puget Sound				Fraser River[1]			
	Springs		Falls		Springs		Falls	
Brood year	Catch	CPUE	Catch	CPUE	Catch	CPUE	Catch	CPUE
1955	6.5	2.76	26.1	4.25	46.5	2.84	56.7	1.78
1956	8.3	3.36	16.5	3.35	54.7	3.19	42.8	2.08
1957	5.0	2.36	20.1	3.78	38.0	2.76	57.4	1.84
1958	4.0	2.71	25.5	4.66	77.4	4.07	71.0	1.51
1959	4.2	2.72	22.7	3.88	63.3	4.48	90.8	2.40
1960	6.1	2.80	34.3	5.10	49.8	3.12	72.2	2.66
1961	7.8	2.90	51.1	5.20	47.0	2.03	45.4	2.22
1962	5.1	2.23	29.2	4.26	57.8	3.33	40.6	2.15
1963	5.4	2.56	55.8	5.43	56.1	4.39	60.3	2.05
1964	6.0	2.63	41.6	5.47	71.6	4.65	81.6	3.46
1965	6.9	2.77	56.3	5.96	46.7	3.17	45.2	2.22
1966	4.1	2.34	55.4	6.90	49.4	4.06	57.7	2.78
1967	1.7	1.62	44.9	5.63	76.5	4.54	53.7	1.76
1968	3.5	2.40	58.2	6.78	55.8	4.63	58.8	2.66
1969	3.6	2.70	52.6	6.82	46.9	4.83	50.1	2.35
1970	2.3	2.51	66.8	8.76	43.6	3.52	96.2	3.77
1971	2.3	2.89	66.9	8.16	54.0	3.85	105.8	2.54

[1]Includes Point Roberts.

Spring chinook salmon:		
Puget Sound	Gill net	1.00
	Set net	0.90
	Drag seine	1.64
	Indian trap	8.79
Point Roberts	Fraser River gill net	1.00
	Washington gill net	0.86
	Washington purse seine	5.44
	Washington reef net	1.72
Fall chinook salmon:		
Puget Sound	Gill net and set net	1.00
	Drag seine	0.91
	Indian trap (1955-61)	11.02
	(1962-75)	3.05
	Purse seine	1.45
Point Roberts	Fraser River gill net	1.00
	Washington gill net	0.80
	Washington set net	1.32

Washington purse seine	3.16
Washington reef net	2.14

Hatchery production.—Releases from Columbia River hatcheries above Bonneville Dam were weighted by subtracting 10% (a generally accepted mortality rate) of the figure reaching each dam downriver of the point of release from the total arriving at the dam, to compensate for juvenile mortality associated with turbine passage. For example, if 10,000 kg were released at a point upriver of three dams, the amount reaching the ocean was estimated at 7,290 kg:

$$\begin{aligned}\text{Dam 1} \ldots\ 10{,}000 - 0.1\ (10{,}000) &= 9{,}000\\ \text{Dam 2} \ldots\ 9{,}000 - 0.1\ (9{,}000) &= 8{,}100\\ \text{Dam 3} \ldots\ 8{,}100 - 0.1\ (8{,}100) &= 7{,}290\end{aligned}$$

Surface sea temperature during period of out-migration.—The studies by Vernon (1958) and Van Hyning (1968) both implicated warm surface sea temperature at Amphitrite Point during June of year $i-2$ as a negative factor affecting juvenile survival. The possibility of a relationship between ocean fishing success and this variable was evaluated by calculating regressions of 1) commercial ocean troll catch, 2) troll CPUE, and 3) ocean sport catch during year i on mean sea temperature there during June and June through August of year $i-2$.

Upwelling during period of out-migration.—We calculated regressions of 1) commercial ocean troll catch, 2) troll CPUE, and 3) Washington ocean sport catch in year i on indices of upwelling during April through June in year $i-2$ off Cascade Head and Cape Flattery. Upwelling indices are listed in Table 4. Since surface salinity is a good indicator of the extent of upwelling (Owen 1968), regressions were calculated of these dependent variables on ranked values (1 = lowest ‰) of salinity at Amphitrite Point during June through August of year $i-2$; the base data are contained in sources listed previously.

Upwelling during current season.—We calculated the regressions of 1) Columbia River district commercial troll catch, 2) Columbia River district troll CPUE, and 3) combined sport catch for Ilwaco and Westport in year i on indices of spring (April-June) upwelling off Cascade Head in year i. Regressions of 1) Puget Sound district commercial troll catch, 2) Puget Sound district troll CPUE, 3) Canadian troll catch in areas C, 21, and 23, and 4) combined sport catch during April through October for La Push and Neah Bay in year i on indices of spring upwelling off Cape Flattery in year i were also calculated.

Table 4.—Indices of upwelling. Modified from Gunsolus (1978).

	Cascade Head		Cape Flattery	
Year	April index	April-June index	April index	April-June index
1960	0	32.5	5	22.0
1961	36	22.0	55	25.5
1962	18	41.0	25	32.0
1963	16	40.0	38	42.0
1964	82	95.5	80	68.5
1965	30	98.5	41	76.5
1966	68	103.5	73	68.0
1967	36	122.5	51	84.3
1968	72	93.0	71	59.5
1969	4	37.0	0	33.0
1970	50	64.5	64	57.5
1971	23	39.5	27	37.5
1972	24	44.5	36	37.0
1973	68	69.0	64	42.0
1974	27	55.0	38	44.0
1975	60	97.0	58	66.0

Previous fishing success.—Several fisheries in the previous year may function as test fisheries for chinook salmon. If the assumption is valid that the troll fishery in Canadian areas 24-27 intercepts southward-bound Columbia River fall chinook salmon in the fall of the year prior to their maturity, then troll CPUE there may be an indication of probable chinook salmon catches off the Washington coast in the following year. The Puget Sound sport catch of chinook salmon is composed mostly of fish 1 yr younger than those caught in the ocean. Annual Puget Sound sport catch in year $i-1$ may then serve as an index of abundance of Puget Sound-Fraser River chinook salmon that will be in the ocean the following year. The Canadian purse seine catch of immature chinook salmon (called jacks in Canadian statistics) in Canadian area 20 during August of year $i-1$ could also be a potential indicator of ocean fishing success the following year. We therefore calculated regressions of troll catch, CPUE, and sport catches on these variables.

Coho Salmon

Indices of brood year abundance.—These consisted of spawner density estimates, escapements, and net gear catch and CPUE during peak run periods (Table 5), based on dates listed below.

Run	*Inclusive dates*
Columbia River	1 October-30 November
Area 20	1 August-31 October
Puget Sound	1 September-31 October
Fraser River	1 September-31 October

Table 5.—Indices of brood year abundance of coho salmon based on net gear catch (in thousands of fish) and CPUE (in fish per standardized unit of effort).

Brood	Late-run Columbia R.		Puget Sound		Combined Puget S., area 20, Fraser R.	
year	Catch	CPUE	Catch	CPUE	Catch	CPUE
1953	14.7	3.71	—	—	665.2	9.8
1954	10.0	4.24	—	—	420.5	6.2
1955	15.0	7.37	297.2	11.3	614.9	7.4
1956	17.1	8.90	453.8	23.4	581.9	17.8
1957	13.8	7.99	187.7	11.7	696.9	10.5
1958	5.4	4.23	266.9	10.7	674.7	8.4
1959	3.3	4.10	255.3	13.3	743.9	10.9
1960	1.1	3.93	80.7	8.5	223.5	6.4
1961	4.0	8.37	330.9	20.2	726.0	14.6
1962	6.5	10.21	352.3	20.5	861.0	17.3
1963	6.4	12.13	175.9	11.9	609.8	9.2
1964	7.0	12.27	344.2	23.4	823.6	20.5
1965	10.4	15.85	325.9	21.6	883.9	17.4
1966	6.8	32.86	572.8	33.7	1,227.1	23.4
1967	8.1	14.42	241.2	14.7	777.3	12.1
1968	3.2	6.21	403.1	25.1	920.9	22.2
1969	3.2	7.71	284.1	18.6	617.5	14.0
1970	29.0	25.88	778.4	36.4	1,402.8	24.4
1971	32.1	18.79	475.5	23.4	1,213.7	16.6
1972	9.0	9.81	522.0	23.1	784.1	16.1

CPUE was calculated as described for pink salmon using the following efficiency factors:

Puget Sound	Gill net, set net, reef net, and drag seine	1.00
	Indian trap	7.36
	Purse seine	1.98
Area 20	Canadian gill net	0.63
	Canadian purse seine	8.46

Hatchery production.—Releases for upper Columbia River hatcheries were adjusted as described for chinook salmon. Senn (1970a, b) showed that the survival rate of coho salmon released from hatcheries in northern Puget Sound is about 50% of that for fish planted by other Puget Sound hatcheries. For Puget Sound hatchery production, only one-half of the aggregate weight of releases from northern hatcheries was included.

Environmental conditions during preemergence.—We calculated regressions of troll catch, troll CPUE, and sport catch in areas north of Cape Elizabeth on rank indices (1 = lowest rate) for pooled peak momentary discharge rates during October (year $i-3$) through February (year $i-2$) in the North Fork of the Stillaguamish, Skykomish, and Puyallup Rivers. Regressions were also computed for the same dependent variables against rank indices (1 = lowest temperature) of pooled air temperatures at Sequim, Puyallup, Darrington, Concrete, Newhalem, Quilcene, and Startup during the winter (October-March) of preemergence.

Summer streamflow during year $i-2$.—Regressions of troll catch and CPUE in areas north of Cape Elizabeth against ranks of the average July-September flow rate in six Puget Sound rearing streams (Newaukem Creek, Wallace River, Cascade River, North Fork of the Stillaguamish River, Skykomish River, and Puyallup River) were calculated. For each stream, average flow rates were ranked from lowest (1) to highest. Then we summed these ranks for each year and ranked the sums to obtain the series of annual indices shown below.

Year	*Streamflow index*	*Year*	*Streamflow index*
1953	14.0	1964	17.0
1954	20.0	1965	8.0
1955	18.0	1966	9.0
1956	13.0	1967	7.0
1957	2.0	1968	15.0
1958	1.0	1969	11.0
1959	19.0	1970	4.5
1960	10.0	1971	16.0
1961	4.5	1972	21.0
1962	12.0	1973	3.0
1963	6.0		

Oceanographic conditions affecting juvenile survival.—To estimate the influence of marine physical conditions upon survival during the first months of ocean residence, we calculated regressions of troll catch and CPUE in areas north of Cape Elizabeth on mean surface sea temperature and salinity at Amphitrite Point during July through September of year $i-1$. Regressions were also calculated of 1) commercial troll catch in the Columbia River and Coastal Washington districts, 2) troll CPUE in the same areas, and 3) combined annual sport catch for Ilwaco and Westport on indices of Cascade Head upwelling during April and April through June of the previous year. Similarly, regressions were computed of 1) commercial ocean troll catch in the Puget Sound and Vancouver Island districts, 2) ocean troll CPUE in these areas, and 3) combined sport catch for La Push and Neah Bay during June through October on indices of Cape Flattery upwelling.

Oceanographic conditions influencing catchability.—Regressions of troll catch, CPUE, and sport catch on indices of upwelling during April and April through June in year *i* were calculated. Also computed were the regressions of 1) monthly troll CPUE in Canadian area 23 against mean surface sea temperature and salinity for the same month at Amphitrite Point and 2) monthly troll CPUE in Canadian area 27 against the corresponding monthly means of surface sea temperature and salinity at Kains Island.

Jack returns.—We computed the regressions of 1) ocean troll catch in the Columbia River and Coastal Washington districts, 2) troll CPUE in the same areas, and 3) combined Ilwaco-Westport sport catch in year *i* on Columbia River jack counts in year $i-1$.

Average individual weight and monthly growth.—The average weight of troll-caught coho salmon was estimated as the aggregate weight of the catch divided by the number of fish. The average monthly weight increments were calculated as

$$\frac{\text{October average weight} - \text{July average weight}}{3}.$$

Then we compared annual troll catch, CPUE, and sport catch in each area with 1) the average individual weight of coho salmon caught there in August and 2) the average monthly weight increment. Also calculated were regressions of monthly troll CPUE on monthly mean individual weight by area.

RESULTS

Models discussed had the highest multiple correlation coefficients and smallest standard error of those developed. For each species, the principal results are summarized, then details are discussed in subsequent paragraphs.

Pink Salmon

1. Troll catch south of Cape Flattery was highly correlated with the level of nominal fishing effort.
2. Troll catches in most areas were significantly correlated with practically all indices of brood year abundance when compared with Ricker curves.
3. Troll catches were highly associated with average individual weight of pink salmon caught in terminal areas in the brood year.

We found no conclusive, consistently significant correlations between indices of ocean fishing success and any environmental factor. The following equation explained 80-85% of the variation in annual troll catch in most areas:

$$\ln R = \ln a - b_1 S + b_2 X + \ln S,$$

where R was troll catch in year i, S was net gear catch in Canadian area 20 during August through September of year $i-2$, and X was average individual weight of pink salmon caught in the Fraser River in September of year $i-2$. The average error of predicted catches from observed catches exceeded $\pm 25\%$ in each area.

Chinook Salmon

1. Troll catches were significantly correlated with levels of nominal fishing effort, particularly prior to the opening of the coho salmon season.
2. Total Washington ocean sport catch was highly associated with the number of angler trips.
3. Annual troll catch off the central Washington coast was highly correlated with the releases of fall chinook salmon of brood year groups $i-3$ and $i-4$ by lower Columbia River hatcheries.
4. Canadian troll catches in area 23 during April through May were significantly associated with releases of fall chinook salmon of brood year groups $i-3$ and $i-4$ by lower Columbia River hatcheries.
5. Annual Washington ocean sport catches were highly correlated with Columbia River hatchery releases of fall chinook salmon of brood year groups $i-3$ and $i-4$.

Levels of Effort.—Troll catches were significantly associated with levels of troll effort, as evidenced by the following correlation coefficients.

Area	*Apr.-May*	*June-Aug.*	*Sept.-Oct.*
Columbia River	0.894	0.651	0.495
Coastal Washington	0.791	0.840	0.764
Puget Sound (Wash.)	0.888	0.749	0.696
Areas C, 21, 23 (Can.)	0.760	0.683	0.727
Areas 24-27 (Can.)	0.691	0.261	0.623

The total Washington ocean sport catch was highly correlated with the total number of angler trips during 1964-75 ($r = 0.938$).

Indices of brood year abundance.—These were of little predictive value. Troll catch and CPUE in most areas were significantly associated with Columbia River upriver fall escapements (combined for years $i-3$ and $i-4$) when data for years prior to 1962 were analyzed separately, but correlations were not significant when data for more recent years were included.

Hatchery production.—Releases of fall chinook salmon of brood year groups $i-3$ and $i-4$ combined by lower Columbia River hatcheries explained more of the variation in troll catch, troll CPUE, and ocean sport catch than did any other factor. Although trends in fall chinook salmon releases have been similar for all major production areas, we have assumed that the Columbia River plant is the principal factor because numerous tag studies have clearly shown that Columbia River fall chinook salmon predominate in the ocean population. Figure 2 illustrates the relationship between troll catches off central Washington and Columbia River hatchery releases. Figure 3 shows the association between Canadian troll catches in area 23 during

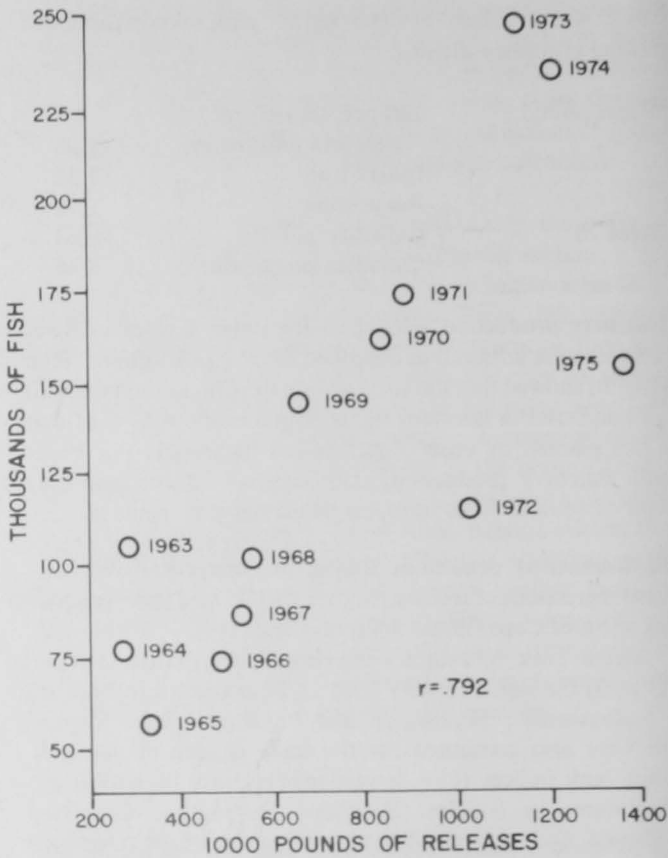

Figure 2.—Annual commercial troll catch of chinook salmon in the Coastal Washington area vs. plant of fall brood year groups $i-3$ and $i-4$ combined by lower Columbia River hatcheries, 1963-75.

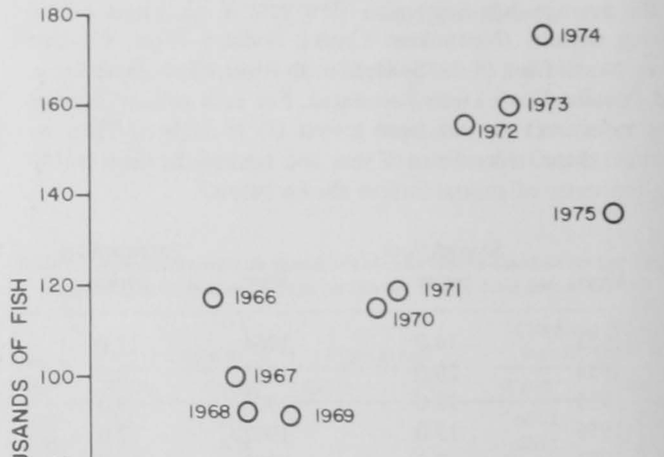

Figure 3.—Canadian commercial troll catch of chinook salmon in areas C, 21, and 23 during April through May vs. plant of fall brood year groups $i-3$ and $i-4$ combined by lower Columbia River hatcheries, 1963-75.

April through May and Columbia River fall chinook salmon releases. The correlation coefficient for the regression of annual Washington ocean sport catch in 1964-75 on total Columbia River fall chinook salmon releases was 0.958. The comparison of actual catches with those predicted from this regression is illustrated graphically in Figure 4.

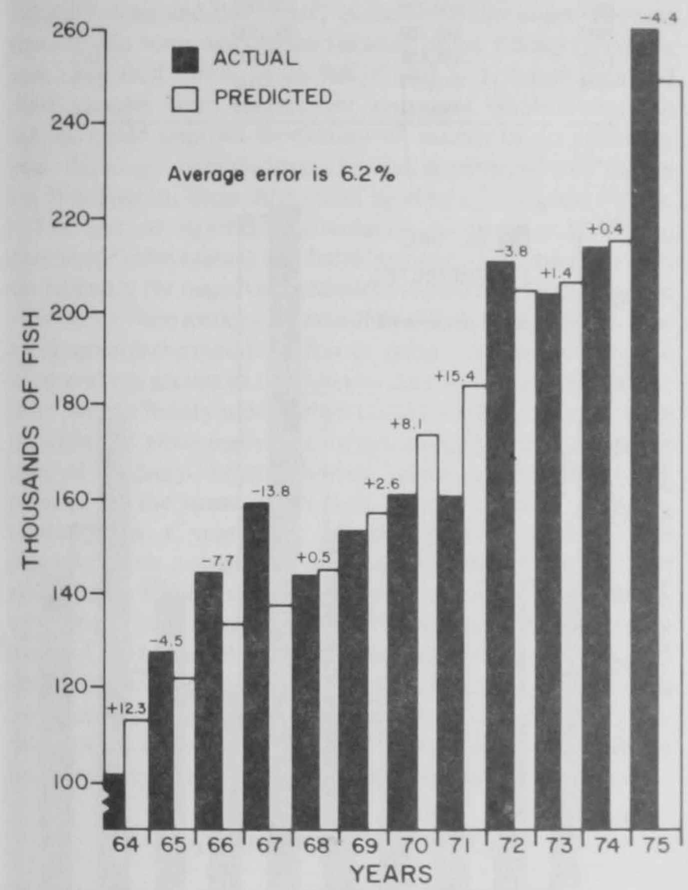

Figure 4.—Annual Washington ocean sport catch of chinook salmon, 1964-75, and that predicted from the regression of catch on total Columbia River hatchery releases of fall chinook salmon of brood year groups $i-3$ and $i-4$ combined. Numbers at the tops of the columns indicate percentage error.

Previous fishing success.—Troll catch and CPUE in most areas were significantly correlated with 1) troll CPUE during September through October of year $i-1$ in the Coastal Washington district, 2) troll CPUE in Canadian areas 24-27 during September through October of year $i-1$, 3) annual Puget Sound sport catch in year $i-1$, and 4) Canadian purse seine catches of jacks during August of year $i-1$ in Canadian area 20. The correlations with Puget Sound sport catch may be serial correlations, since this variable was highly correlated with Columbia River fall hatchery releases. Although the area 20 purse seine catches were also highly associated with Columbia River hatchery releases, they may be of predictive value as an indicator of hatchery plant survival. For example, Figure 5 illustrates the relationship between early season Canadian troll catches and the natural log of numbers of jacks caught. Correlation coefficients for the regressions of 1) annual Washington ocean sport catch and 2) La Push-Neah Bay sport catch during April through October in 1964-75 on logs of jack catches were 0.887 and 0.913, respectively.

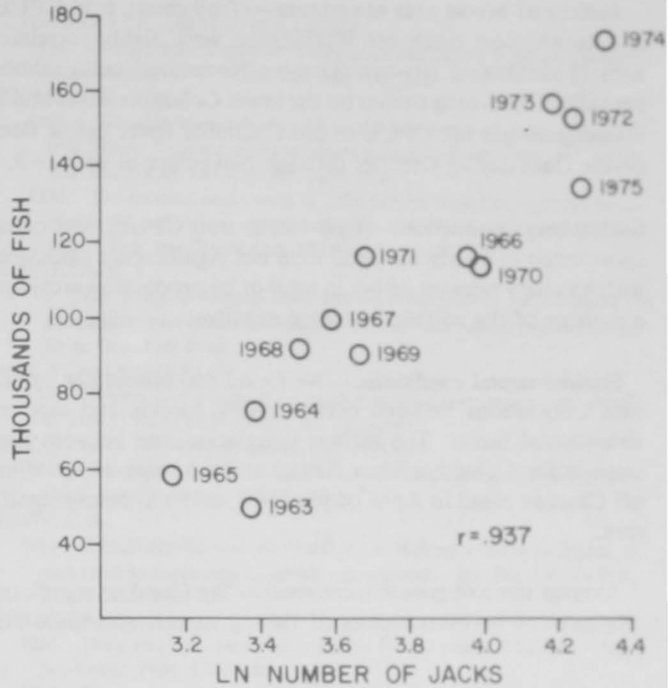

Figure 5.—Canadian commercial troll catch of chinook salmon in areas C, 21, and 23 during April through May vs. natural log of number of jacks in the area 20 purse seine catch during August of year $i-1$, 1963-75.

Prediction of ocean catches.—A simple linear regression with lower Columbia River hatchery releases of fall chinook salmon of brood year groups $i-3$ and $i-4$ combined as the independent variable was the best predictive method.

Coho Salmon

1. Troll catches were significantly correlated with levels of nominal fishing effort.
2. There were no significant associations between ocean sport catches and the number of angler trips.
3. Troll and sport catches were significantly correlated with indices of brood year abundance of late-run Columbia River coho salmon in Ricker curves.
4. Troll catches off southern and central Washington were significantly correlated with Columbia River jack returns the previous year.
5. Ocean fishing success was not significantly correlated with indices of hatchery production, either in total or on an area-by-area basis.

Levels of effort.—Troll catches were significantly correlated with levels of troll effort during 1955-75, as indicated by the correlation coefficients listed below. In contrast, we found no significant associations between sport catches and the number of angler trips.

Area	*June-August*
Columbia River	0.800
Coastal Washington	0.880
Puget Sound (Washington)	0.603
Areas C, 21, 23 (Canadian)	0.865
Areas 24-27 (Canadian)	0.802

Indices of brood year abundance.—Troll catch, troll CPUE, and ocean sport catch off Washington were highly correlated with 1) number of late-run (October-November) coho salmon per mile of spawning stream on the lower Columbia River and 2) Washington gill net CPUE in the Columbia River below Bonneville Dam during October through November in year $i-3$.

Hatchery production.—Troll catch, troll CPUE, and ocean sport catch in nearly all areas were not significantly associated with hatchery releases (either in total or by production area) and a number of the correlations were negative.

Environmental conditions.—We found no consistently significant associations between ocean fishing success and any environmental factor. The highest correlation was between troll catch in the Columbia River district and the index of upwelling off Cascade Head in April of year $i-1$, and was nearly significant.

Average size and growth increments.—We found no significant relationships between indices of fishing success and these factors.

Jack counts.—Troll catches off the central and southern Washington coast were significantly associated with Columbia River jack returns in the previous year.

Prediction of ocean catches.—Most of the Washington ocean catch is made south of La Push. The best predictive equation for annual troll catch in the Columbia River district was

$$\ln R = \ln a - 0.4334S + 0.0111X_1 + 0.0057X_2 + \ln S \quad (2)$$

where R was troll catch in year i, S was the count of late-run Columbia River coho salmon per mile of spawning stream in year $i-3$, X_1 was the Columbia River jack count in year $i-1$, and X_2 was the index of upwelling off Cascade Head during April of year $i-1$. This multiple regression explained 89% of the variation in annual troll catch during 1966-75, with an average percentage error of the predicted catches of ±15% (Table 6). The best model for annual troll catch in the Coastal Washington district was

$$\ln R = \ln a - 0.0642S + 0.0078X_1 + \ln S \quad (3)$$

where R was annual catch and S and X_1 were as defined above. This regression also accounted for about 89% of the variation in troll catch during 1966-75, with an average error of about ±21% (Table 7). Figure 6 illustrates the comparison of the predicted catches combined for both districts with the catches actually reported.

Table 6.—Comparison of annual coho salmon troll catches in the Columbia River district with those predicted from Equation (2).

Year	Actual catch (fish)	Predicted catch (fish)	Percentage error
1966	183,731	162,500	−11.6
1967	236,429	235,500	− 0.4
1968	184,825	178,000	− 3.7
1969	157,791	167,500	+ 6.2
1970	205,541	243,500	+18.5
1971	469,629	427,500	− 9.0
1972	216,233	163,000	−24.6
1973	103,715	155,000	+49.4
1974	186,230	207,000	+11.2
1975	159,810	131,000	−18.0

Table 7.—Comparison of annual coho salmon troll catches in the Coastal Washington district with those predicted from Equation (3).

Year	Actual catch (fish)	Predicted catch (fish)	Percentage error
1966	431,592	448,500	+ 3.9
1967	360,046	278,000	−22.8
1968	377,690	461,500	+22.2
1969	200,665	283,500	+41.3
1970	475,657	624,000	+31.2
1971	640,230	672,000	+ 5.0
1972	248,329	292,500	+17.8
1973	484,833	333,500	−31.2
1974	642,614	476,000	−25.9
1975	453,620	395,500	−12.8

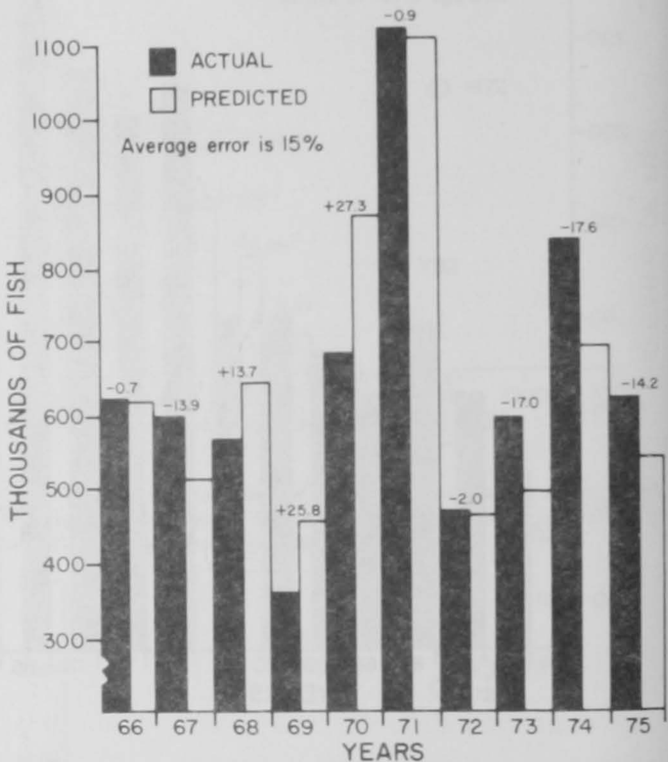

Figure 6.—Annual commercial catch of coho salmon in the Columbia River and Coastal Washington areas, 1966-75 and that predicted from Equations (2) and (3). Numbers at the tops of the columns indicate percentage error.

DISCUSSION

Although ocean fishing success for pink salmon is roughly associated with brood year abundance of major stocks, the relationship has little predictive value for specific ocean fishing areas. The relative abundance and contribution of each stock in such areas probably vary widely in different cycle years. Until stock composition in specific ocean areas is better defined, the predictive value of spawner-recruit models based on brood year abundance of specific stocks will remain limited. The rate of ocean exploitation is increasing and, combined with extreme fluctuations in cycle year abundance, makes accurate forecasting of ocean catches of pink salmon very difficult.

Similar time trends in fishing effort and hatchery production, combined with high intercorrelations between the most useful independent variables, affect the reliability of ocean chinook salmon catch predictions based on simple regressions. The importance of lower Columbia River hatchery production of fall chinook salmon to the fishery off Washington and southwestern Vancouver Island is difficult to dispute, however, based on both mark-tag recaptures and the close association between ocean fishing success and this factor, as shown in this paper. Because there is also some association between ocean fishing success in year i and troll CPUE in the fall of year $i-1$, length data and scale samples from troll-caught immature (shaker) chinook salmon could improve predictions of catches in the following year. Although there no longer is a fall commercial troll fishery off Washington, these data could be obtained in a test fishery.

The lack of significant association between ocean fishing success for coho salmon and hatchery production, together with the tendency for negative correlation, is puzzling, particularly in view of the close association noted for fall chinook salmon. One explanation is the masking effect resulting from the contribution of several age groups to the chinook salmon fishery, whereas the coho salmon fishery is dependent upon a single age group. Thus the effect of abnormally high ocean mortality on a single year class of hatchery-released chinook salmon is less likely to be reflected in the ocean catch than is the impact of a similar mortality on a year class of coho salmon releases. This dependence on a single age group does facilitate prediction of ocean coho salmon catches, however, when a variable (e.g., upwelling or jack count) reflective of probable ocean survival is included in the model. Although the pink salmon catch is also obtained from a single age group, the coho salmon catch does not fluctuate to the extremes observed for pink salmon. Of the three species considered here, coho salmon appear to offer the best prospect for reasonably accurate prediction of ocean catch.

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