Effects of Streamflow and Upwelling on Yield of Wild Coho Salmon (*Oncorhynchus kisutch*) in Oregon

DENNIS L. SCARNECCHIA[1]

Oregon Cooperative Fishery Research Unit,[2] Oregon State University, Corvallis, OR 97331, USA

SCARNECCHIA, D. L. 1981. Effects of streamflow and upwelling on yield of wild coho salmon (*Oncorhynchus kisutch*) in Oregon. Can. J. Fish. Aquat. Sci. 38: 471–475.

To investigate the dependence of coho salmon (*Oncorhynchus kisutch*) yield on streamflow and oceanic upwelling, I regressed catch by the Oregon commercial troll fishery from 1942 to 1962 against indices of offshore upwelling the previous spring and measurements of streamflow from five Oregon coastal rivers during the freshwater rearing phase. A highly significant positive relation was found between total streamflows during the freshwater residency of the fish for the five rivers combined and the weight of the annual catch of coho salmon from 1942 to 1962. There was also a significant positive relation between total combined annual (January–December) flows for these rivers and the catch 2 yr later. Conversely, I found no significant relation between the 60 consecutive days of lowest flow during summer and catch 2 yr later. High flows during freshwater rearing probably provide more habitat and better conditions for growth and survival. I also found a significant positive relation between April through June upwelling at two stations and catch of coho salmon the following year from 1947 to 1962. Fifty-six percent of the variation in catch from 1947 to 1962 was explained by the total flows during freshwater residency, 60 consecutive days of lowest flow, plus combined April through June upwelling at both stations. It is suggested that some stocks of coho salmon smolts may move southward or remain in local offshore waters after they enter the ocean to take advantage of the production of invertebrates resulting from upwelling.

Key words: streamflow, upwelling, coho salmon, Oregon coast

SCARNECCHIA, D. L. 1981. Effects of streamflow and upwelling on yield of wild coho salmon (*Oncorhynchus kisutch*) in Oregon. Can. J. Fish. Aquat. Sci. 38: 471–475.

Dans l'étude décrite ci-dessous de la dépendance du rendement en saumons coho (*Oncorhynchus kisutch*) du débit des cours d'eau et de la remontée d'eaux profondes dans l'océan, nous avons calculé la régression des prises dans la pêche commerciale aux lignes traînantes de l'Orégon entre 1942 et 1962 contre les indices des remontées d'eaux profondes au large le printemps précédent et le débit de cinq rivières côtières de l'Orégon pendant la phase en eau douce des saumons. Il y a corrélation fortement positive entre le débit total des cours d'eau à l'époque où les poissons résident dans les cinq rivières combinées et le poids des prises annuelles de saumons coho entre 1942 et 1962. Il y a également une corrélation positive significative entre le débit annuel combiné total (janvier–décembre) de ces rivières et les prises 2 ans plus tard. Inversement, nous n'avons pas trouvé de relation significative entre les 60 jours suivant l'étiage estival et les prises 2 ans plus tard. De forts débits pendant la phase de croissance en eau douce fournissent probablement un habitat plus étendu et de meilleures conditions de croissance et de survie. Nous avons aussi trouvé une corrélation positive significative entre la remontée d'eaux profondes d'avril à juin, à deux stations et les prises l'année suivante, entre 1947 et 1962. Cinquante-six pour cent de la variation des prises de 1947 à 1962 s'explique par le débit total pendant la phase de résidence en eau douce, 60 jours après l'étiage, plus la remontée d'eaux profondes combinés entre avril et juin inclusivement aux deux stations. Il est possible que certains stocks de smolts de saumon coho se déplacent vers le sud ou demeurent dans les eaux du large locales une fois descendus à la

[1]Present address: Colorado Cooperative Fishery Research Unit, Colorado State University, Fort Collins, CO 80523, USA.
[2]Cooperators are the Oregon Department of Fish and Wildlife, U.S. Fish and Wildlife Service, and Oregon State University.

Printed in Canada (J6085)
Imprimé au Canada (J6085)

mer de façon à tirer profit de la production d'invertébrés résultant de la remontée d'eaux profondes.

Received May 21, 1980
Accepted December 3, 1980

Reçu le 21 mai 1980
Accepté le 3 décembre 1980

YEARLY abundance and yield of coho salmon (*Oncorhynchus kisutch*) have historically fluctuated widely. Ability to predict coho salmon abundance before the fishing season enables fishermen to allocate time and money efficiently and allows biologists to recommend harvest rates that will prevent overfishing of stocks.

Inasmuch as catches of coho salmon on neighboring rivers tend to fluctuate together (McKernan et al. 1950; Tollefson 1959), biologists have searched for widespread environmental factors influencing abundance. One approach to predicting abundance before the fishing season is to correlate environmental variables with the catch of adult coho salmon by either terminal fisheries or troll fisheries. Neave (1949) reported a significant correlation between number of coho salmon caught per 100 hours of sport fishing in Cowichan Bay, British Columbia, and minimum summer streamflows 2 yr earlier.[3] Smoker (1955) found the combined annual runoff from 21 watersheds in western Washington to be highly correlated with total combined catch of coho salmon 2 yr later by the commercial fisheries of Puget Sound, Willapa Bay, and Gray's Harbor. Smoker also obtained significant correlations between summer flow, as well as lowest monthly flow, and catch 2 yr later. He concluded that these flows merely reflected annual flows. He was unable to show significant correlations between streamflow and catch for most individual rivers. The Washington Department of Fisheries now estimates the number of wild coho salmon returning to Puget Sound streams by using summer streamflows of western Washington 2 yr before the catch (Zillges 1977).

It has been assumed that available rearing area during low summer flows limits most coho salmon populations in Washington. However, Wood (1977) found poor correlations between low summer flows of western Washington coastal streams and the size of the ensuing runs.

Little is known about how variable oceanic factors affect survival of coho salmon from smoltification to maturity. Royal and Tully (1961) found that marine survival rates of sockeye salmon (*Oncorhynchus nerka*) ranged from 4 to 18%.

Upwelling is one oceanic factor which may affect survival of coho salmon. Upwelling occurs off Oregon primarily from April to September, and results from northerly winds blowing down the coast as they circulate clockwise around the large high-pressure system over the Pacific Ocean (Smith et al. 1966; Cushing 1971; Bakun 1973). During this time, cold, nutrient-rich, high-salinity water (Lynn 1967) is transported upward where nutrients support primary production. The lower temperatures and increase in primary production lead to an increase in the standing crop of zooplankton (Murphy 1961) which is consumed by many species of commercially important fish.

Upwelling affects the distribution and abundance of many species of fish. Sardines (*Sardinops sagax*) and anchovies (*Engraulis mordax*) utilize upwelled water for spawning and rearing (Ahlstrom 1966, 1967; Cushing 1971). Barton (1979) presented data indicating that upwelling may have influenced survival of Columbia River and Lemhi River spring chinook salmon (*Oncorhynchus tshawytscha*). Gunsolus (1978) found a positive relation between upwelling off Oregon and growth and survival of coho salmon from 1960 to 1975.

For coho salmon, I postulated that if upwelling affects survival, it would exert this effect primarily on smolts, and not on larger salmon, since Gunsolus' (1978) data indicate that survival of Oregon's hatchery-reared coho salmon during their final year in the ocean is fairly constant.

Upon reaching the ocean, the smolts have adjusted physiologically and behaviorally and begin feeding on pelagic invertebrates. Since coho salmon in Oregon emigrate from streams in April (Skeesick 1970) and May (Willis 1962), I postulated that spring and summer (April–September) was the critical period for marine survival of coho salmon smolts.

My objectives were (1) to determine if a correlation existed between coho salmon catch and annual streamflows, summer streamflows, and total streamflows during the freshwater rearing phase; (2) to determine if a correlation existed between both April–June and June–September upwelling and catch of coho salmon the following year; and (3) to relate the combined effects of streamflows and upwelling to subsequent catch of adult salmon by the commercial troll fishery.

Materials and methods — Streamflow records summarizing mean daily discharge for five coastal rivers — the Nehalem, Wilson, Siletz, Alsea, and Coquille — were obtained from U.S. Geological Survey reports for Oregon (1939–70; 1971–73). These five rivers were selected for study for three reasons: (1) data on daily streamflow were recorded on each river since 1939; (2) records of catch of coho salmon by the offshore fishery were recorded when corresponding data on streamflow were recorded; and (3) the rivers historically have supported substantial populations of coho salmon.

Low summer streamflows were measured as the sum of mean daily flows for the 60 consecutive days of lowest flows in each of the rivers. All other flows were expressed as sums of combined unweighted monthly discharges for the five rivers. All flows were expressed as $m^3 \cdot s^{-1}$. The period 1942–62 was chosen for analysis of catch and streamflow relations because streamflow data were unavailable before 1939 for two of the five rivers, and the period preceded the years of large returns of hatchery fish to the Columbia River (Korn 1977).

Upwelling data from 42°N, 125°W, off southern Oregon,

[3]Most coho salmon are age 1.1 where number left and right of the decimal indicate number of marine and freshwater annuli on their scales, respectively. If coho salmon are caught as age 1.1 adults in year x, they were fry in streams in year x-2 and yearlings in year x-1. Their parents probably spawned from about November, x-3, to January, x-2.

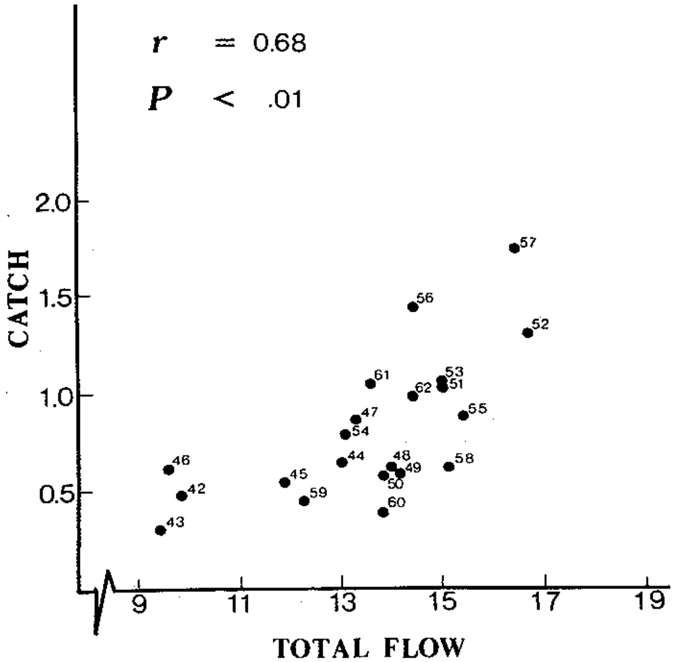

FIG. 1. Total November (x-3) through May (x-1) flows ($\times 10^9 m^3 \cdot s^{-1}$) for five coastal rivers combined versus weight (kg $\times 10^6$) of coho salmon caught in year x by the Oregon commercial troll fishery. Catch data extend from 1942 to 1962. Catch ($\times 10^{-3}$) = $-894.5236 + 0.1256$ (flow) ($\times 10^{-6}$).

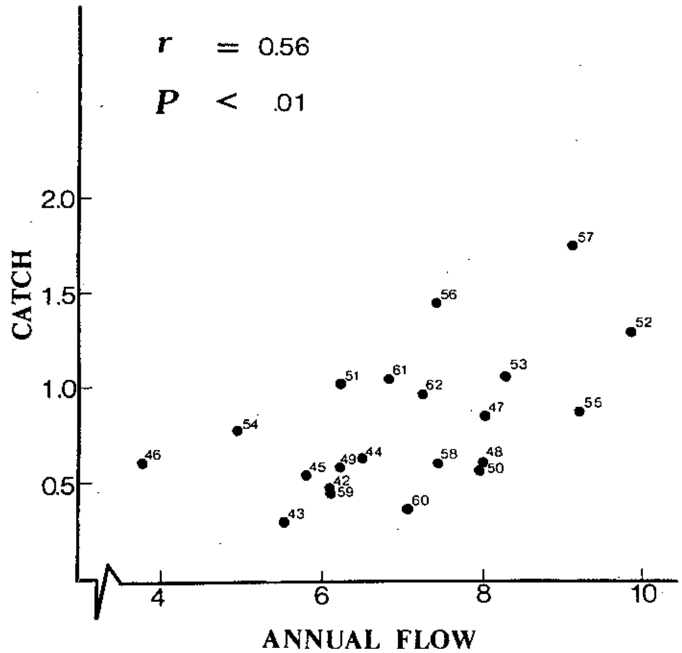

FIG. 2. Total annual flows ($\times 10^9 m^3 \cdot s^{-1}$) for five coastal rivers combined versus weight (kg $\times 10^6$) of coho salmon caught 2 yr later by the Oregon commercial troll fishery. Catch data extend from 1942 to 1962. Catch ($\times 10^{-3}$) = $-176.4991 + 0.1395$ (flow) ($\times 10^{-6}$).

and from 45°N, 125°W, off northern Oregon, were obtained from Bakun (1973). The indices are based on monthly means of atmospheric pressure fields from which winds and resultant upwelling were estimated. Upwelling is expressed as $kg \cdot s^{-1} \cdot 100\ m^{-1}$ of coastline. Data were unavailable from either station before 1946.

Yield was expressed as weight of the catch in kilograms rather than as numbers of fish caught because numbers of fish were not recorded before 1952. From 1952 to 1962, numbers and weight were closely correlated ($r = 0.98$).

I performed simple and multiple linear regression analyses on catch, flow, and upwelling data using the Statistical Interactive Programming System (SIPS) of the CDC 3300 computer at Oregon State University, Corvallis.

Results — A significant relation was found between total November (x-3) through May (x-1) streamflows for the five coastal rivers combined and weight of coho salmon caught by the Oregon commercial troll fishery in year x from 1942 to 1962 (Fig. 1). This 19-mo period of streamflow, from November to May 2 yr later, corresponds to the time from entrance of adult salmon into coastal rivers to the seaward migration of their progeny as smolts (Willis 1962; Moring and Lantz 1975). There was also a highly significant relation between total annual flow and catch 2 yr later (Fig. 2). The 60 consecutive days of lowest flow for the five rivers combined correlated poorly with annual flows ($r = 0.20$; $P > 0.05$) and with November (x-3) through May (x-1) flows ($r = 0.13$; $P > 0.05$). Though the relation between annual flows with catch 2 yr later was highly significant, the relation between the 60 consecutive days of lowest flow and catch 2 yr later was poor ($r = 0.28$; $P > 0.05$).

A significant relation was found between combined April (x-1) through June (x-1) upwelling at both stations and catch from 1947 to 1962 (Fig. 3). Similar significant relations were also found between catch and upwelling at each station separately ($r = 0.57$; $P < 0.05$ for 42°N, 125°W; $r = 0.54$; $P < 0.05$ for 45°N, 125°W). Midsummer upwelling (June–September) did not significantly relate to catch ($r = 0.34$; $P > 0.05$).

Since total November (x-3) through May (x-1) flows and 60 consecutive days of lowest flow were poorly correlated, I calculated a multiple regression of these flows and April (x-1) through June (x-1) upwelling at both stations versus catch from 1947 to 1962. Fifty-six percent of the variation in catch was explained (Fig. 4). The multiple regression equation was:

$$\text{Catch} (\times 10^{-3}) = -1853.0589 + 0.1499 \times 10^{-6} (\text{total flow}) + 0.3823 (\text{low flow}) + 0.00109 (\text{upwelling}).$$

Sixty-four percent of the variation in catch was explained when 1960, the year of lowest catch, was excluded from the analysis.

Discussion — Although neither low summer flows nor upwelling entered significantly in the multiple regression analysis, both were included in the model. Low summer flows and low upwelling may decrease abundance of coho salmon, yet average summer flows and upwelling may not directly relate to abundance. In any year, I believe any of the three factors included in the model could limit abundance. Summer flows and upwelling together explained an additional 15% of

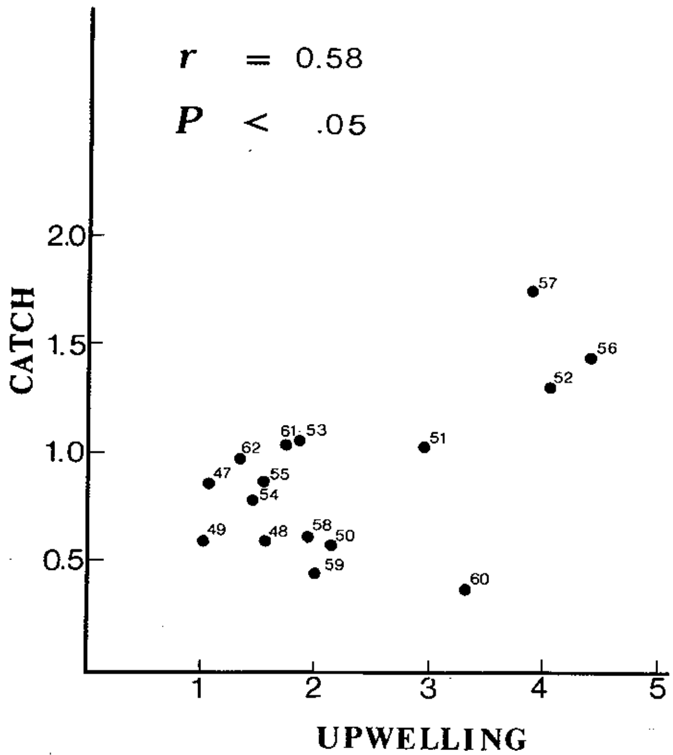

FIG. 3. Sum of total April through June upwelling indices at 42°N, 125°W, and 45°N, 125°W ($\times\ 10^6$ kg·s^{-1}·100 m^{-1} of coastline) off of Oregon versus weight (kg $\times\ 10^6$) of coho salmon caught 1 yr later by the Oregon commercial troll fishery. Catch data extend from 1947 to 1962. Catch ($\times\ 10^{-3}$) = 450.2993 + 0.00197 (upwelling).

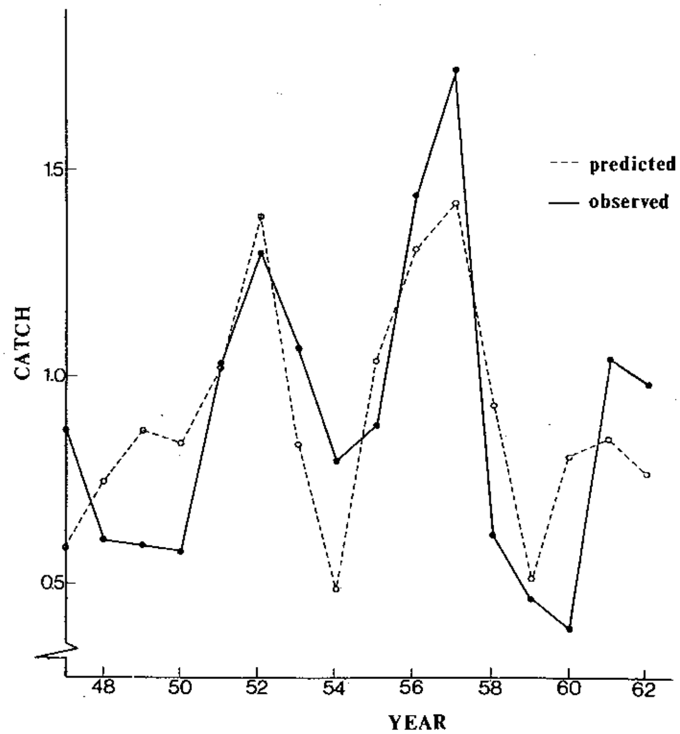

FIG. 4. Predicted and observed catch of coho salmon in kilograms by the Oregon commercial troll fishery from 1947 to 1962.

the variation in catch after the total flow variable entered the model.

The relation between total annual flows and catch of coho salmon 2 yr later is noteworthy, since Smoker (1955) found a similar relation between annual flows and catch of coho salmon in western Washington from 1935 to 1954, an overlapping but not identical time span. Before large numbers of smolts were released from hatcheries, a quantity of streamflow in coastal rivers influenced abundance and subsequent yield of coho salmon.

For Oregon coastal rivers, summer streamflows were not related to annual flows, although Smoker (1955) found a close relation between them in Washington. This difference between Oregon and Washington streams probably results from a difference in timing of runoff. The watersheds analyzed by Smoker were fed by melting snow and glaciers in summer, and high precipitation in winter often led to high streamflows the following summer, whereas the five Oregon rivers that I studied flow out of the Coast Range mountains, which receive nearly all precipitation in winter as rain. In these rivers, summer flows are mainly dependent on quantity of precipitation in summer.

High streamflows when adult spawners are entering rivers may allow access to upper spawning areas and may result in greater production of smolts in upper tributaries (Allen 1969). Higher flows may also increase the area of spawning beds. Of course, eggs spawned in gravel inundated by high flows may die if flows drop before fry emerge.

Higher flows and resultant higher velocities can cause individual Atlantic salmon to occupy smaller territories (Kalleberg 1958). Consequently, higher flows during time of emergence through the summer may lead to more space, more cover, and, in turn, to a higher density of young salmon in streams. The number of juveniles surviving low summer flows may depend on their initial numbers. In years when the number of fry is large before the period of low flow, more fish may survive the low flows, although the individuals may be smaller than in years of low numbers (L. S. Pearson, K. R. Conover, and R. E. Sams, Oregon Fish Commission, unpublished data).

From 1963 to 1972, the correlation between total annual flows and catch by the troll fishery was poor ($r = 0.24$; $P > 0.05$), as expected. During this period, hatchery fish were contributing significantly to the fishery, as indicated by returns of salmon to the Columbia River hatcheries (Korn 1977). Since hatchery fish are not reared in streams, other factors probably affect their return, e.g. oceanic factors, diseases, or the "quality" of smolts released (expressed as potential for growth and survival in the ocean).

Little is known about oceanic movements of coho salmon smolts. Loeffel and Forster (1970) corroborated the hypothesis of northward movement along the coast during summer. However, if upwelling affects survival of coho salmon, many smolts may move southward or remain nearby along the coast to use the available food.

Study is needed on oceanic feeding of coho salmon during their 1st year and the relation between food supply, upwelling, and survival of smolts. Upwelling may increase production of small invertebrates, and thereby increase growth and survival of larval fishes and large invertebrates, which may also serve as food for smolts. A causal link must be established between response of food organisms to upwelling and response of salmon to food organisms.

At present, I can only speculate about why upwelling may influence survival of year-classes of coho salmon. It seems unlikely that smolts would die of starvation in years of little upwelling. Perhaps in these years growth is reduced because food is scarcer. Smaller, slower-growing smolts may remain susceptible to predation longer than larger smolts. Larger, faster-growing fish with a greater supply of food may resist diseases better than poorly fed fish. Availability of abundant food may be crucial for growth and survival following the physiological adjustments coho salmon undergo during smoltification.

Although catch may poorly indicate abundance of adult fish, the troll fishery is the most reliable source of data on abundance available for comparisons with flow. Since this fishery gets the first opportunity to catch migrating coho salmon and has been virtually unregulated since its inception (Van Hyning 1951; Reed 1976), catch is probably more indicative of actual abundance than data from individual rivers.

I advise caution in using these findings predictively. Since the mid-1960s hatchery fish have made up a substantial percentage of coho salmon caught offshore (Korn 1977). Scarnecchia and Wagner (1980) estimated that ~75% of the coho salmon caught offshore in 1977 were reared in hatcheries. The unknown interaction between the wild and hatchery fish may alter the relationships presented. Other oceanographic factors may have changed since then. Present escapement of coho salmon may be inadequate because of heavy fishing pressure in recent years.

Acknowledgments — I thank J. D. Hall, J. Lichatowich, S. B. Mathews, J. D. McIntyre, W. A. Smoker, A. V. Tyler, H. H. Wagner, and others for offering valuable comments, and C. Alexander of the U.S. Geological Survey for providing data on streamflows.

AHLSTROM, E. H. 1966. Distribution and abundance of sardine and anchovy larvae in the California current region off California and Baja California, 1951–64: a summary. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 534: 71 p.

1967. Co-occurrences of sardine and anchovy larvae in the California current region off California and Baja California. Calif. Mar. Res. Comm., Calif. Coop. Fish. Invest. Rep. 11: 117–135.

ALLEN, K. R. 1969. Limitations on production of salmonid populations in streams, p. 3–18. *In* T. G. Northcote [ed.] Symposium on salmon and trout in streams. H. R. MacMillan lectures in fisheries. University of British Columbia, Vancouver, B.C.

BAKUN, A. 1973. Coastal upwelling indices, west coast of North America, 1946–1971. Nat. Oceanic Atmos. Adm. Tech. Rep. SSRF-671: 103 p.

BARTON, A. C. K. 1979. Factors influencing the life history of spring chinook salmon (*Oncorhynchus tshawytscha*) spawning in the Columbia River watershed from 1960 to 1977. Ph.D. thesis, Oregon State Univ., Corvallis, OR. 243 p.

CUSHING, D. H. 1971. Upwelling and the production of fish. Adv. Mar. Biol. 9: 255–334.

GUNSOLUS, R. T. 1978. The status of Oregon coho and recommendations for managing the production, harvest, and escapement of wild and hatchery-reared stocks. Oreg. Dep. Fish Wildl. Rep. 59 p.

KALLEBERG, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout (*Salmo salar*, L. and *S. trutta*, L.). Inst. Freshwater Res. Drottningholm Rep. 39: 55–98.

KORN, L. 1977. Information on Columbia River salmon runs and fisheries. Int. North Pac. Fish. Comm. Bull. 36: 1–14.

LOEFFEL, R. E., AND W. O. FORSTER. 1970. Determination of movement and identity of stocks of coho salmon in the ocean using the radionuclide zinc-65. Fish Comm. Oreg. Res. Rep. 2(1): 1–13.

LYNN, R. J. 1967. Seasonal variation of temperature and salinity at 10 meters in the California current. Calif. Mar. Res. Comm. Calif. Coop. Fish. Invest. Rep. 11: 157–174.

MCKERNAN, D. L., D. R. JOHNSON, AND J. I. HODGES. 1950. Some factors influencing trends of salmon populations in Oregon. Trans. North Am. Wildl. Conf. 15: 427–449.

MORING, J. R., AND R. L. LANTZ. 1975. The Alsea Watershed study: effects of logging on the aquatic resources of three headwater streams of the Alsea River Oregon. Part one — biological studies. Oreg. Dep. Fish Wildl. Fish. Res. Rep. 9: 66 p.

MURPHY, G. I. 1961. Oceanography and variations in the Pacific sardine population. Calif. Mar. Res. Comm. Calif. Coop. Fish. Invest. Rep. 8: 55–64.

NEAVE, F. 1949. Game fish populations in the Cowichan River. Bull. Fish. Res. Board Can. 84: 32 p.

REED, P. H. 1976. A history and current status of Oregon ocean salmon fisheries — troll salmon investigations. Oreg. Dep. Fish Wildl. Rep. 20 p.

ROYAL, L. A., AND J. P. TULLY. 1961. Relationship of variable oceanographic factors to migration and survival of Fraser River salmon. Calif. Mar. Res. Comm. Calif. Coop. Fish. Invest. Rep. 8: 65–68.

SCARNECCHIA, D. L., AND H. H. WAGNER. 1980. Contribution of wild and hatchery-reared coho salmon, *Oncorhynchus kisutch*, to the Oregon ocean sport fishery. Fish. Bull. 77(3): 617–623.

SKEESICK, D. G. 1970. The fall immigration of juvenile coho salmon into a small tributary. Fish. Comm. Oreg. Res. Rep. 2: 1–6.

SMITH, R. L., J. G. PATTULLO, AND R. K. LANE. 1966. An investigation of the early stage of upwelling along the Oregon coast. J. Geophys. Res. 71(4): 1135–1140.

SMOKER, W. A. 1955. Effects of streamflow on silver salmon production in western Washington. Ph.D. thesis, Univ. of Washington, Seattle, WA. 175 p.

TOLLEFSON, R. 1959. A summary of fishery statistics of the Pacific coast. Northwest Pulp and Paper Association. 182 p.

U.S. GEOLOGICAL SURVEY. 1939–70. Water Supply papers No. 884, 904, 934, 964, 984, 1014, 1044, 1064, 1094, 1124, 1154, 1184, 1218, 1248, 1288, 1348, 1398, 1448, 1518, 1568, 1638, 1718, 1935, 2135. Superintendent of Documents, Washington, D.C.

1971–73. Water Resources data for Oregon. Superintendent of Documents, Washington, D.C.

VAN HYNING, J. M. 1951. The ocean salmon troll fishery of Oregon. Oreg. Fish Comm. Contrib. 15: 46–76.

WILLIS, R. A. 1962. Gnat Creek weir studies. Oreg. Fish. Comm. Rep. 71 p.

WOOD, W. 1977. Methods of estimating escapement requirements, preseason run size, and in-season run size of north coastal salmon stocks. Wash. Dep. Fish. Rep. 7 p.

ZILLGES, G. 1977. Methodology for determining Puget Sound coho escapement goals, escapement estimates, 1977 pre-season run size prediction and inseason run assessment. Wash. Dep. Fish. Tech. Rep. 28: 65 p.