The Columbia River — Toward a Holistic Understanding

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Abstract

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The Columbia River is one of the world's great rivers. It supports large runs of anadromous fish — several species of Pacific salmon and steelhead trout. Its watershed covers 671 000 km^2, including parts of British Columbia, Washington, Oregon, Idaho, Montana, and Wyoming, and the average annual flow rate at the river's outlet is about 6 655m^3• s^{-1}. Hydroelectric power, irrigation, and exploitation of regional resources other than water have greatly modified physical features throughout the Columbia River's vast system. Commercial and sport fishing, combined with alteration and degradation of riverine habitat, have reduced annual returns of anadromous fish from about 10 to 16 million originally to 2.5 million today. Efforts by management agencies to deal with the declines have focused on catch restriction, fish passage problems at dams, artificial propagation, habitat improvement, and identification of stocks at sea. Today, management is a joint effort by federal, regional, and state agencies and Indian tribes. Increased returns of anadromous fish to the river since 1980 are encouraging, but much remains to be done.

Résumé

EBEL, W. J., C. D. BECKER, J. W. MULLAN, AND H. L. RAYMOND. 1989. The Columbia River — toward a holistic understanding, p. 205–219. *In* D. P. Dodge [ed.] Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106.

Le Columbia est l'un des grands fleuves du monde. Il s'y fait d'importantes remontées anadromes (plusieurs espèces de saumons du Pacifique et la truite arc-en-ciel). Il a un bassin hydrologique de 671 000 km^2, qui recouvre des parties de la Colombie-Britannique et des États de Washington, de l'Orégon, de l'Idaho, du Montana, et du Wyoming; il a un débit annuel moyen de 6655 m^3•s^{-1}. Les ouvrages hydro-électriques, l'irrigation et l'exploitation des ressources régionales autres que l'eau ont profondément modifié les traits physiques dans l'ensemble de ce vaste bassin. Les pêches commerciales et sportives, en plus de la transformation et de la dégradation des habitats riverains, ont eu pour effet de réduire les remontées annuelles, de 10 à 16 millions à l'origine jusqu'à 2,5 millions aujourd'hui. En réaction, les organismes de réglementation ont fait porter leurs efforts sur les limites de capture, les problèmes de remonte aux barrages, la multiplication par des moyens artificiels, la remise en état de l'habitat et l'identification des stocks en mer. La gestion des stocks est devenue une entreprise conjointe où sont réunis les efforts des gouvernements fédéral et régionaux, des services d'États et des bandes indiennes. Les remontées plus abondantes dans le fleuve depuis 1980 sont encourageantes, mais il reste encore beaucoup de travail à faire.

Introduction

The Columbia River is one of the world's great rivers. It drains 671 000 km^2, (259 000 mi^2) and discharges over twice the amount of water as the Nile River in Egypt. The Columbia River also produces large runs of Pacific salmon (*Oncorhynchus* spp.) and steelhead trout (*Salmo gairdneri*), and has served as a focal point for the evolution of northwest native cultures dependent on these fish. The river's discovery in 1792 by Captain Robert Gray and its exploration in 1805 by Lewis and Clark set in motion changes that profoundly altered the river and its watershed.

The river's capacity for sustained production of salmonids was greatest prior to 1930. Before encroachment by white settlers, the aboriginal fishery was estimated to take about 8.2×10^6 kg (18 million lb) (Craig and Hacker 1950) or 11.3×10^6 kg (25 million lb) (Hewes 1972) of fish each year. During the peak period of commercial fishing (1916 to 1920), catches exceeded 18.1×10^6 kg (40 million lb) each year. Even today, with the runs depressed, the annual combined catch of commercial, sport, and tribal fisheries exceeds 9.1×10^6 kg (20 million lb).

In terms of numbers, salmon and steelhead runs ranged from about 10 to 16 million fish, annually before major development of the Columbia River Basin (Northwest Power Planning Council 1986). Current runs average about 2.5 million fish, indicating that basin-wide losses have been about 7 to 14 million fish. Chief Joseph Dam on the Columbia River and Hells Canyon Dam on a major tributary, the Snake River, blocked return runs, and eliminated all habitat for anadromous fish production above them. Declines in runs of anadromous fish have been greatest in the upper Columbia and Snake rivers because of habitat loss and mortalities of upstream and downstream migrants at dams.

The history of the Pacific Northwest is marked by conflicts among fishermen, and between fishermen and other users over control of the Columbia River. Overfishing and resource allocation have been continuing problems. Economic development has, over the years, degraded or eliminated habitat and thereby decreased the system's capacity to produce anadromous fish. Hydropower leads the list, but agriculture and irrigation, logging, mining, stream channelization and clearing, and water pollution have all altered the river's ecosystem.

In this report, we first describe the ecological features of the Columbia River. We then focus on the salmonid resources: commercial and sport fisheries, effects of regional development and exploitation, smolt passage problems, artificial propagation, and institutional arrangements for management. We review needs and opportunities related to salmonid production.

Morphometry

The Columbia River begins at Columbia Lake in the Canadian Rockies. The river flows northwesterly in British Columbia for about 306 km (190 mi), then south 436 km (271 mi) across the Okanogan Highlands to Trail, British Columbia. It continues south across the international border to receive the Spokane River, then curves westward over the semi-arid Columbia Plateau to receive the Snake River near the Washington/Oregon border. At this point, the river turns west and flows about 483 km (300 mi) through the Cascade and Coast ranges to enter the Pacific Ocean near Astoria, Oregon (Fig. 1).

From source to outlet, the Columbia River extends over 1930 km (1200 mi) and drops 808 m (2650 ft). It passes through four mountain ranges: the Rockies, Selkirks, Cascades, and Coast; traverses several climatic zones from alpine to shrub-steppe to coastal; and receives flows from several large tributaries before discharging to the sea. The Snake River, the largest tributary, extends 1671 km (1038 mi) and drains 49% of the system's watershed in the United States.

The Cascade Range forms a mountainous barrier to the passage of moisture inland from the Pacific Ocean. East of the Cascades is an open landscape, the Columbia Plateau, which was formed over millions of years from discontinuous flows of lava that solidified as basalt in nearly horizontal layers. As a result, parts of the mainstem Columbia and Snake rivers are entrenched in spectacular gorges.

Hydrology

The Columbia's average annual flow rate at its outlet is about 6655 $m^3 \cdot s^{-1}$ (235 000 $ft^3 \cdot s^{-1}$). Discharges from the Snake River average about 1300 $m^3 \cdot s^{-1}$ (46 000 $ft^3 \cdot s^{-1}$) annually (Pacific Northwest Regional Commission 1979). Nearly 25% of the Columbia's total runoff originates west of the Cascade Range, an area less than 10% of the total drainage, because of its higher precipitation.

Major tributaries of the mainstem Columbia River are: the Kootenai and Pend Oreille rivers in Canada; the Spokane, Okanogan, Wenatchee, Yakima, Snake, Cowlitz, and Lewis rivers in Washington; and the Umatilla, John Day, Deschutes, and Willamette rivers in Oregon. The interior drainage area extends to Idaho, Montana, and Wyoming.

In general, tributaries of the Columbia River originate in high, forested mountains where the climate is mesic, the gradient is steep, stream velocity is high, and scouring occurs. In the Columbia Basin proper, the climate is xeric, the gradient is less steep, stream flow is reduced, and sediment is deposited seasonally. The Cascade Range near the river's mouth is forested and receives heavy rainfall.

The main factors influencing hydrographs of Columbia River tributaries are changes in seasonal runoff and irrigation withdrawals. Hydrographs of the mainstem are influenced primarily by storage and release of water from impoundments for hydroelectric power production.

Mainstem Flow Regimes

Spring flows in the Columbia River are triggered by snowmelt and rain in headwater areas. Precipitation, primarily in the form of snow, is greatest in winter, and runoff increases with snowmelt during spring and early summer. Most major floods on tributaries east of the Cascades result from rapid snowmelt. The most severe spates are often accentuated by heavy, warm rain or warm wind. Convective storms accompanied by intense rainfall may also cause local floods.

Before impoundment of the mainstem, estimated discharges at the river's outlet averaged 18 690 $m^3 \cdot s^{-1}$ (660 000 $ft^3 \cdot s^{-1}$) from May through July and 1980 $m^3 \cdot s^{-1}$ (70 000 $ft^3 \cdot s^{-1}$) from September through March (Hickson and Rodolf 1957). Today, flows throughout the Columbia's drainage area are influenced by water storage projects. by 1973, the combined storage of Mica, Duncan, Arrow, Albeni Falls, Libby, Hungry Horse, and Grand Coulee dams (Fig. 1) provided capacity to store over 43 200 x $10^6 \cdot m^3$ of spring runoff for use later in the year when more electricity is needed. As a result, in most years,

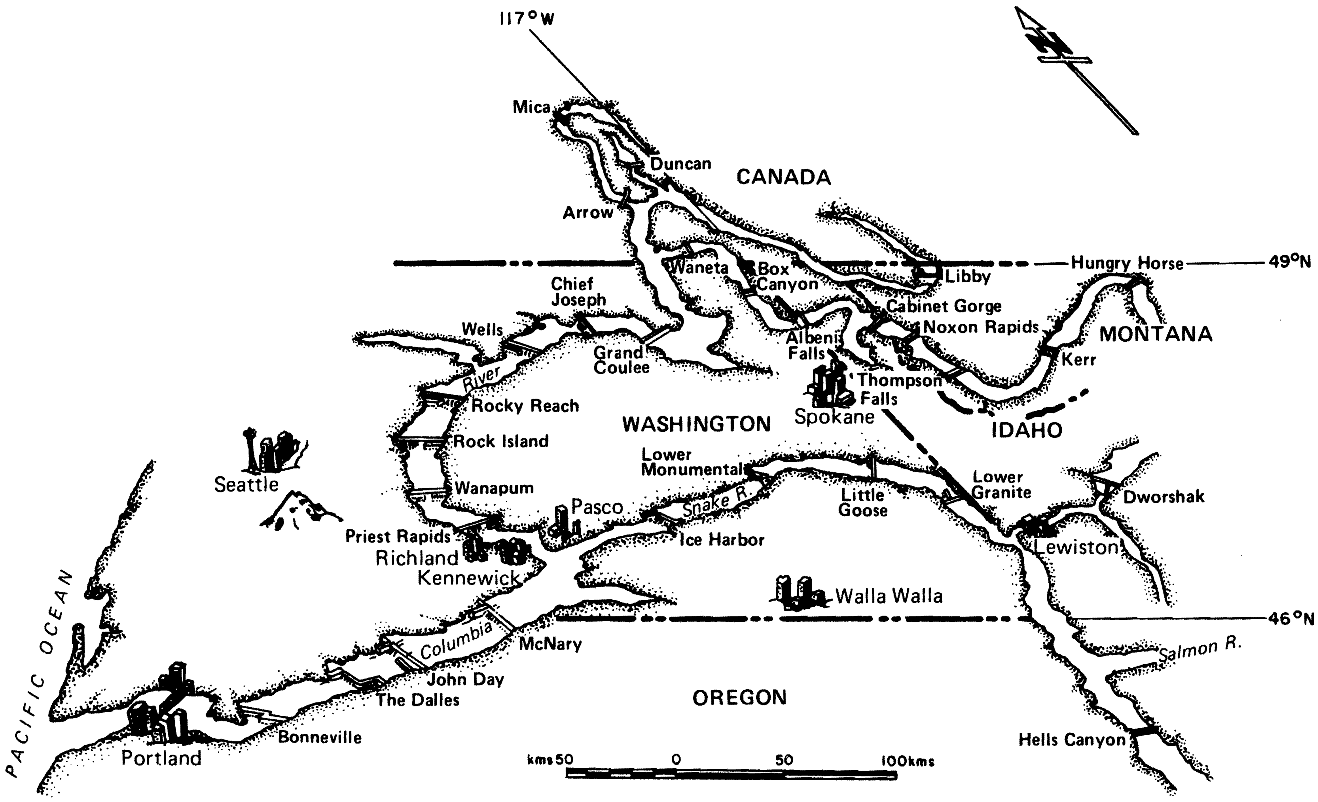

FIG. 1. The Columbia River system, showing the major tributaries, dams, and major metropolitan centers.

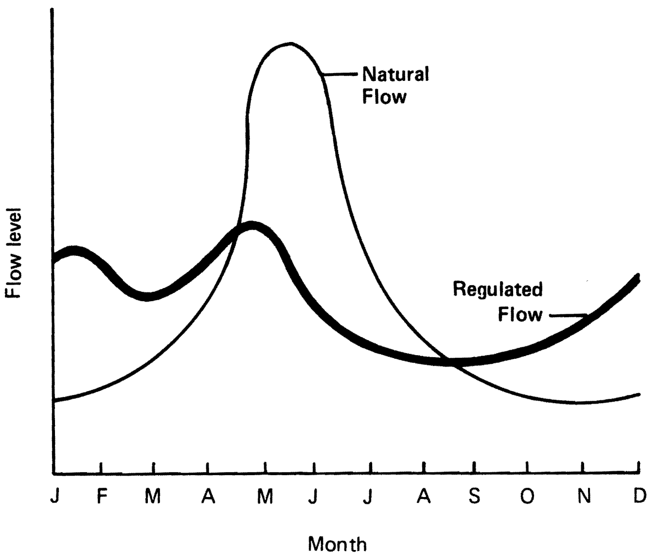

FIG. 2. Generalized effect of reservoir operations on mainstem Columbia River flows near The Dalles, Oregon. Tributary storage of water and mainstem production of hydropower eliminated the spring peak runoff that once transported juvenile salmonids downstream to the Pacific Ocean.

flows in the Columbia River when young salmonids migrate to sea in May and June have been reduced about 50% (Fig. 2). The system's total "active storage" capacity of 53 800 x $10^6 \cdot m^3$ represents about a quarter of the average annual runoff (Table 1).

Lake McNaughton of the Mica Project in Canada is the largest storage reservoir on the Columbia River system, and it may remain unfilled after seasonal drawdown. The Arrow Lakes in Canada are also used primarily for storage. Lake Roosevelt, behind Grand Coulee Dam, is the major storage reservoir in the United States; it contains 6400 x $10^6 \cdot m^3$) of active storage but has a total volume of 11 800 x $10^6 \cdot m^3$. Essentially, the whole mainstem below Lake Roosevelt is influenced by the storage and hydraulic capacities of Grand Coulee Dam.

The flushing rate of Lake Roosevelt is about 45 days. Below Grand Coulee Dam, flushing rates for river-run reservoirs vary from less than 1 day (Priest Rapids) to about 4 days (Lake Wallula). Current velocities in these impoundments average about 0.3 $m \cdot s^{-1}$. Lake Umatilla is primarily a storage reservoir, but it has a flushing rate of about 7 days.

Most storage reservoirs undergo major seasonal drawdown. For example, the elevation of Lake Roosevelt is lowered about 25 m (82 ft) each year prior to the spring spate (Stober et al. 1979). In contrast, water levels of most river-run reservoirs may fluctuate 0.3 to 1.5 m (1 to 5 ft) daily in response to power generation at their outlet dams.

The last unimpounded section of the mainstem of the Columbia River is the Hanford Reach, a 80.5 km (50 mi) section between the head of Lake Wallula and Priest Rapids Dam. It is not "free-flowing," but regulated by discharges at and above Priest Rapids Dam.

Discharge volumes from mainstem dams generally increase downstream. This is because of reduced reservoir storage ratios and increments of water from tributaries. Annual discharges at Bonneville Dam average near 164 000

TABLE 1. Storage characteristics of mainstem Columbia River reservoirs.

Dam	Reservoir (lake)	Location (RKM)	Length (km)	Total volume[a] $(\times 10^6 \cdot m^3)$	Mean annual discharge $(\times 10^6 \cdot m^3 \cdot {}^{-}yr^{-1})$	Storage ratio[b]	Flushing rate (days)[c]
Mica	McNaughton	1638	209	25 040	18 260	1.37	499
Revelstoke	—	1498	129	1 480	70 440	0.02	7.3
Keenleyside	Arrow	1255	216	9 250	35 775	0.26	94
Grand Coulee	F. D. Roosevelt	960	243	11 800	96 220	0.12	45
Chief Joseph	Rufus Woods	877	71	616	96 470	0.007	2.6
Wells	Pateros	830	45	370	100 420	0.004	—
Rocky Reach	Entiat	761	68	493	102 390	0.005	1.8
Rock Island	Rock Island	729	34	123	105 600	0.001	—
Wanapum	Wanapum	668	61	740	105 600	0.007	2.6
Priest Rapids	Priest Rapids	639	29	247	105 720	0.002	0.7
McNary	Wallula	470	98	1 727	150 995	0.011	4.0
John Day	Umatilla	348	122	3 084	153 960	0.020	7.3
The Dalles	Celilo	309	39	370	158 890	0.003	1.1
Bonneville	Bonneville	325	72	616	163 700	0.004	1.5

[a] Total volume (table data) represents the maximum capacity of water storage in a reservoir, and is significant ecologically. Active storage (text data) represents only the storage capacity sufficient to provide daily or weekly streamflow regulations.

[b] Storage ratio (annual) = $\dfrac{\text{Total volume}}{\text{Mean annual discharge rate}}$

This is also called the exchange rate or flushing rate, and has a value in years, convertible to days.

[c] Flushing rate = annual storage ratio × 365 (days). This is the number of days required, theoretically, to completely empty a reservoir at the mean annual discharge rate.

$\times 10^6 \cdot m^3$. Also, reservoirs on the lower Columbia River are the widest and shallowest of the Columbia River system. The mean depth of Lake McNaughton near the river's origin is 58.5 m (192 ft), but Lake Bonneville near the river's outlet averages only 9 m (30 ft) deep. Flows below Bonneville Dam are under tidal influence.

Sedimentation

The drainage basin of the Columbia River contains a variety of igneous, metamorphic, and sedimentary rocks, as well as unconsolidated surficial deposits from ancient glaciers. Upstream, the sediments in Grand Coulee, Rocky Reach, Wanapum, and Priest Rapids reservoirs, are largely fine-grained, nonvolcanic, and carried in suspension (Whetten et al. 1969). Downstream, the sediments in Umatilla, Celilo, and Bonneville reservoirs are coarser, of andesitic volcanic origin, and make up most of the bedload. Erosion in the headwaters tends to be rapid because most andesitic formations are poorly consolidated and the local gradient is steep.

Amounts of suspended sediment in the mainstem of the Columbia river vary seasonally with input from tributaries, of which the Snake River is the greatest contributor. Most sediment is transported downstream during a few days or weeks of high spring discharge. During average or low flows, sediment is deposited in impoundments and slackwater areas. Much of this material is resuspended during high flows. Thus, maximum sediment loads enter the pacific Ocean during late spring and early summer, the period of maximum water discharge (Whetten et al. 1969).

Little sediment accumulates on the bed of the Columbia River except in slackwater areas and below Bonneville Dam. The river bed between reservoirs is either scoured to bedrock or covered with a thin deposit of coarse gravel. Bedload transport is evident only in the lower Columbia River and the amount transported is probably small, about 10% of the total sediment load exclusive of dissolved materials (Whetten et al. 1969).

The Columbia River discharges about 10^7 t of sediment each year (Nittrouer et al. 1979). However, fine sediment is not deposited to any extent in the Columbia River estuary. Substrate in the estuary consists of about 1% gravel, 84% sand, 13% silt, and 2% clay; silt accumulates in only about 10% of the estuary (Hubbell et al. 1972). Beyond the estuary, bottom currents along the shore remain northward throughout the year. Thus, most sediment leaving the Columbia River is carried northward. Sand tends to accumulate nearshore at <60 m depth, and most silt settles on the midshelf at the 60- to 120-m depth (McManus 1972).

Water Quality

The State of Washington has designated the mainstem of the Columbia River as Class A, or excellent, for water quality standards. This designation means that the water is suitable for use by the public, industry, and agriculture; for rearing livestock, fish, and shellfish; and for wildlife habitat, recreation, and navigation.

Water in the Columbia River is a dilute calcium–magnesium, carbonate–bicarbonate type, with a total dissolved solids content of about 90 $mg \cdot L^{-1}$ (range 71 to 158 $mg \cdot L^{-1}$), from the international border downstream to the confluence with the Snake River. Tributaries that drain the eastern parts of the Columbia Plateau are more mineralized from extensive irrigation and the higher amounts of solutes available from semi-arid land. Consequently, moderately higher mineralization of the mainstem of the Columbia occurs below the outlet of the Snake River.

Water quality in some tributaries used extensively for irrigation may be degraded by return flows from agricultural lands. For example, the lower portion of the Yakima River is seasonally laden with nutrients, pesticides, and coliform bacteria, and reaches temperatures about 4°C above levels expected otherwise. The outlets of the Okanogan and Umatilla rivers show similar impairment (Stober et al. 1979).

Mainstem Temperatures

Temperatures in the Columbia River are lowest in January and February and highest in August and September. The river is warmest near its outlet, where temperatures usually peak near 21°C. Thermal regimes in tributaries throughout the drainage basin differ widely with location, elevation, and input from rainfall, snowmelt, glaciers, and aquifers.

Studies in the 1960's showed that the construction of river-run reservoirs on the mainstem of the Columbia River caused no significant changes in the average annual water temperature. However, storage and release of water from Lake Roosevelt had delayed the timing of peak summer temperatures below Grand Coulee Dam since 1941. This delay was about 30 days at Rock Island Dam and was reflected, to a lesser extent, as far downstream as Bonneville Dam near the river's outlet. Temperature extremes were moderated by the reservoir complex so that the river below Grand Coulee Dam today is slightly cooler in summer and slightly warmer in winter (Jaske and Goebel 1967; Jaske and Synoground 1970).

Historically, average temperatures at the mouth of the Snake River during August and September have always been a few degrees higher than those in the mainstem Columbia (Roebeck et al. 1954; Jaske and Synoground 1970). During late summer of some years, high water temperatures (20° to 22°C) and low dissolved oxygen levels ($<6\ mg \cdot L^{-1}$) make living conditions marginal for salmonids in lower Snake River reservoirs (Bennett et al. 1983).

Productive Potential

Reservoirs strongly affect energy dynamics in the mainstem of the Columbia River. Thermal stratification is restricted in river-run reservoirs, and their relatively high flushing rates limit primary productivity. Thermal stratification occurs seasonally in the lower end of Lake Roosevelt behind Grand Coulee Dam, which also has a definite density-flow regime (Jaske and Snyder 1967; Stober et al. 1977). The lower end of Brownlee Reservoir on the Snake River also stratifies thermally during the summer (Raleigh and Ebel 1968), but reservoirs on the lower Snake River merely develop thermal layering (Bennett et al. 1983).

Development of plankton populations in mainstem impoundments depends, among other things, on water retention in relation to seasonal temperatures. Density and stability of plankton are maximum in reservoirs with long retention times such as Lake Roosevelt and Brownlee Reservoir. Development of indigenous plankton populations in Rufus Woods Reservoir is limited by flushing times of less than four days (Erickson et al. 1977).

Primary Production

Allochthonous detritus is the main contributor of organic material in forested tributaries of the Columbia River. However, a proportionally large population of autochthonous primary producers occurs in the mainstem today. Primary producers in the mainstem of the Columbia River originate largely in reservoirs and are essentially transient, passing from one impoundment to the other at rates related to water retention times. In large part, lentic forms of primary producers pass downstream while periphytic forms are retained. Some periphyton are dislodged by fluctuations of water levels in reservoirs and in the Hanford Reach, and these also pass downstream.

The Upper Arrow, Lower Arrow, and McNaughton reservoirs in Canada are oligotrophic with dissolved oxygen near saturation at all depths. Nutrient levels are low, as is typical of oligotrophic lakes, and diatoms are the dominant phytoplankton. Thermal stratification in these lakes is limited and may not occur in most years (B.C. Research 1977).

Diatoms are predominant in reservoirs in the mainstem of the Columbia River below the international border. Abundance usually peaks in April to June, followed by a second, lesser peak in September to October. Average primary production during the growing season (May to October) in the forebay of Lake Roosevelt is $620\ mg\ C \cdot m^{-2} \cdot d^{-1}$ (Stober et al. 1977). Carbon uptake values in the flowing Hanford Reach amount to $792\ mg\ C \cdot m^{-2} \cdot d^{-1}$ during June and September, but drop to near zero during the winter (Neitzel et al. 1982a). Most phytoplankton (and zooplankton) in the Hanford Reach originate above Priest Rapids Dam and are in transit downstream.

Phosphate, nitrate, and silica concentrations in the mainstem show a definite seasonal change, peaking in the winter and falling in the summer. The summer minima are greatly affected by primary productivity. Near Clatskani, Oregon, below the city of Portland, the nitrate–phosphate ratio is 3:1 during the summer and 19:1 at other seasons (Park et al. 1970).

Zooplankton

Zooplankton reach peak abundance in reservoirs in the mainstem of the Columbia River from June to September, but densities are relatively low the rest of the year. The main zooplankton species are the cladocerans *Bosmina longirostris* and *Daphnia* spp., and the copepods *Cyclops bicuspidatus* and *Diaptomus ashlandi*.

Zooplankton densities peak near 50 000 (Earnest et al. 1966) and 60 000 organisms$\cdot m^{-3}$ (Stober at al. 1977) in Lake Roosevelt; 25 195$\cdot m^{-3}$ in Rufus Woods Reservoir (Erickson et al. 1977); 4500$\cdot m^{-3}$ in the Hanford Reach (Neitzel et al. 1982b); and 12 500$\cdot m^{-3}$ in the lower Columbia River (Clark and Snyder 1970).

Secondary Production

Benthic communities in reservoirs in the mainstem of the Columbia River are dominated by populations of chironomids and oligochaetes (Stober et al. 1979; Beckman et al. 1985), but other benthic organisms may be abundant locally. The benthos is usually depleted in littoral zones where water levels fluctuate.

In the flowing Hanford Reach, caddisfly (Trichoptera) larvae (primarily *Hydropsyche cockerelli*), chironomid larvae, an encrusting sponge, annelids, and the crayfish

Pacifasticus leniusculus are common, but species diversity is low. Historically, the unimpounded Columbia River probably supported an average-to-rich bottom fauna in which caddisfly and chironomid larvae, mayfly nymphs, and molluscs predominated (Roebeck et al. 1954). Today, biomass estimates of benthic invertebrates in the Hanford Reach range from 6 to 237 $g \cdot m^{-2}$ during the winter period of maximum abundance (Beak Consultants, Inc. 1980).

General Productivity

The impounded Columbia River probably has greater primary productivity today than it did when still free-flowing. Mainstem reservoirs allow some development of plankton and periphyton populations, and additional nutrients are added from exogenous sources such as irrigation return water. Increased productive potential is paralleled by a general increase in the diversity and abundance of non-salmonid consumers in downstream impoundments (Mullan et al. 1986).

The period of highest primary productivity in mainstem Columbia River impoundments (June to September) may benefit juvenile salmonids that linger in them during outmigration. Some O-age chinook salmon (*0. tshawytscha*) now feed and grow in McNary, Umatilla, and John Day reservoirs (Miller and Sims 1984). The success of the fall chinook salmon population spawning in the Hanford Reach may depend, in part, on this enhancement to their nursery area.

Fish Species

At least 43 species of fish occur in the mid-Columbia River (Gray and Dauble 1977). While anadromous salmon and steelhead runs are the most important, the Columbia River has other valued fishery resources. Commercial species include the anadromous eulachon (*Thaleichthys pacificus*) and American shad (*Alosa sapidissima*), and a resident population of white sturgeon (*Acipenser transmontanus*). Sport catches include native salmonids such as cutthroat trout (*Salmo clarki*), rainbow trout, and mountain whitefish (*Prosopium williamsoni*), as well as introduced species such as largemouth (*Micropterus salmoides*) and smallmouth bass *M. dolomieui*), walleye (*Stizostedion vitreum*), yellow perch (*Perca flavescens*), crappie (*Pomoxis* spp.), and catfish (*Ictalurus* spp.).

Salmonid Resources of the Columbia River

The expanse of the Columbia River system and the anadromous life cycle of the Pacific salmons and steelhead trout tend,to mask direct cause-and-effect relationships. In some cases, even heavy harvest in the lower river and ocean did not reduce return runs until spawning and rearing habitats were lost and mortality of smolts passing downstream had increased. Adverse effects occurred in varying degrees over several years, and an observable impact on any particular stock did not appear until successive generations, years later. Further, many stocks spawned in widely separated areas, making discovery of low returns more difficult.

Inordinately broad space and time scales contributed, in part, to policital attitudes and laws promoting development of natural resources in the Columbia River Basin — of which water for irrigation and power was the most vital. The salmon and steelhead runs, and the people who depended on them, received little consideration until recent years. Today, anadromous salmonids, hydroelectric power generation, and resource developments in the Columbia River Basin are interrelated to an extent unequaled anywhere.

The following sections provide insight into fishery management problems. The effect of regional resource development on anadromous salmonids, and concurrent present and potential solutions to these problems are described.

Commercial and Sport Fisheries

Runs of salmon and steelhead to the Columbia River have declined over the years. Landings of chinook salmon, for which the Columbia River is most famous, reflect this trend. They show: (1) an estimated peak catch of 2.3 million fish (19.5×10^6 kg) in 1883, followed by a decline until 1889; (2) catches of around 1.5 million fish (11.3×10^6 kg) annually until 1920; and (3) a decline until 1959, with only about 0.3 million fish landed each year from 1960 to 1980, mostly fall chinook salmon (Fig. 3).

From the 1860's to 1900, commercial fisheries in the lower 322 km of the Columbia River concentrated on and soon depleted runs of high quality chinook salmon from the peak summer return. Catches then shifted to the early "spring" and later "fall" runs (Thompson 1951). Today, returns of chinook salmon to the Columbia River are still separated into distinct spring, summer, and fall runs.

As early as 1878, the Columbia River was closed to commercial fishing during March, April, late August, and early September. Resourceful fishermen soon discovered that salmon could be harvested by trolling in the ocean off the river's mouth. An estimated 500 boats were involved in the new troll fishery in 1915. By 1975, about 3300 troll vessels were licensed in Washington; 2000 in Oregon; 2500 in California; and 1400 in British Columbia. Then, as today, many trollers were licensed in more than one state or province, and made extended trips to other fishing areas. Also, the ability of trollers to catch salmon vastly improved as

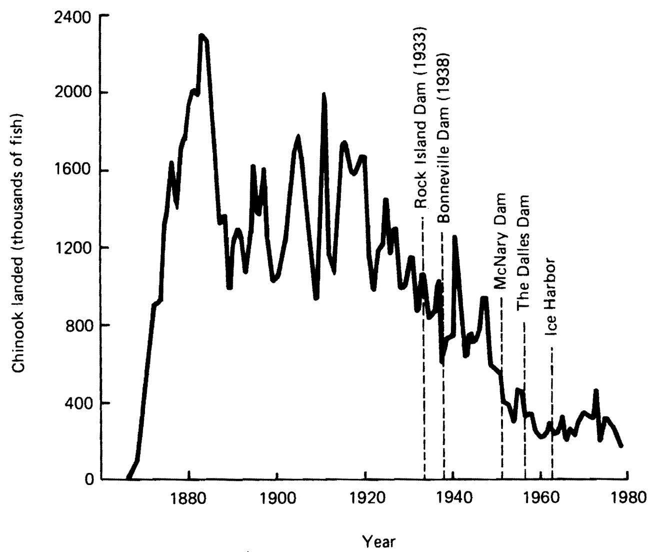

FIG. 3. Landing of chinook salmon by the Columbia River commercial fishery, 1866 to 1979 (from Chapman et al. 1982).

their range expanded and as gear efficiency improved.

Sport fisheries also expanded, albeit more slowly. By the late 1950's and 1960's, sport fishing became a major factor in reducing numbers of adult salmon and steelhead returning to the Columbia River.

Native Indian tribes have traditionally fished return runs in the mainstem Columbia River and various tributaries. Since 1979, certain treaty tribes have been legally entitled to 50% of the allowable harvest. This fishery takes place primarily above Bonneville Dam.

By the early 1930's, the number of adult salmon and steelhead in the annual returns had fallen precipitously (Fig. 3). Concern for the fate of both fish and fishermen led to a patchwork of management organizations and a tangle of state regulations. The early organizations were ill-equipped to manage migratory fish that crossed and recrossed regulatory boundaries. At the same time, new problems arose as hydroelectric dams were built on the mainstem of the Columbia River. However, completion of Bonneville Dam on the lower Columbia River in 1938 gave management a new tool — they could now enumerate adult returns and obtain good estimates of escapement size for each species and run.

In retrospect, three factors contributed to reduced catches of chinook and coho (*O. kisutch*) salmon before 1960: (1) overfishing; (2) decreased production of juveniles, resulting from loss and degradation of spawning/rearing areas; and (3) mortalities of upstream and downstream migrants at dams. Also, hatcheries built prior to 1960 had limited success in compensating for reduced natural production.

Few data exist before the 1960's on the contribution of sport fishing to the total harvest. From this point, the rise in ocean sport catches reflected increased popularity and expansion of the fishery, and more extensive and successful hatchery operations (Chaney and Perry 1976). Sport fishermen caught nearly 500 000 coho salmon of Columbia River origin in 1971 and 200 000 chinook salmon in 1976. Most of these catches were fish of hatchery origin.

Today, salmonids from the Columbia River are caught in the ocean from Monterey, California, to southeastern Alaska. They range widely in the ocean and freely cross political boundaries. Thus, different runs are harvested according to their dispersal patterns. Fall chinook salmon from the lower Columbia River dominate the ocean troll catches from central Oregon to mid-Vancouver Island. Fall chinook salmon from the upper Columbia River migrate farther north and are harvested heavily in waters off British Columbia and Alaska. The chinook salmon from the depleted summer run generally move north (Chapman et al. 1982; Fraidenburg and Lincoln 1985). Spring chinook salmon from the upper Columbia River move north of the river's outlet, whereas those from the Snake River go both north and south (Wahle et al. 1981). Coho salmon from the lower Columbia River are caught mainly off the coasts of California, Oregon, and Washington. In contrast, sockeye salmon (*O. nerka*) and steelhead are not greatly exploited at sea.

Regulating the harvest of mixed stocks of salmonids in the ocean remains a major management problem. Identification of individual stocks or specific fish by stream of origin is difficult. When summer chinook salmon from the Salmon River, Idaho, reach the ocean, they intermingle with runs of summer, spring, and fall chinook salmon from different streams along the Pacific coast. The mixed stocks, each composed of several age groups, are harvested by fishermen from Alaska, British Columbia, Washington, Oregon, and California. Thus, fish from weak runs may be caught along with fish from strong runs--runs still abundant enough to support sport and commercial catches.

Regional Exploitation and Development

As the fisheries expanded, physical changes began to affect adversely salmonid populations of the Columbia River. Exploitation of natural resources proceeded rapidly after 1830, but substantial impacts on salmon runs were not clearly documented until after 1902. In that year, President Theodore Roosevelt's administration passed the Reclamation Act, which eventually led to 28 major reclamation projects.

Economic growth in the Columbia Basin was inevitable. Regional development eliminated or altered fish habitat, caused fish passage and pollution problems, and imposed major constraints on anadromous fish runs.

Dam Construction and Operation

Dams were built primarily for irrigation and power, but they also enhanced navigation, flood control, recreation, and industrial production. The Grand Coulee project on the Columbia River and the Brownlee project on the Snake River had major impacts on salmonid runs. Grand Coulee Dam, operational since 1941, was built without fish ladders and thus prevented access for anadromous fish to over 1100 miles of habitat in the upper Columbia River. Brownlee Dam, operational in 1958, terminated all fish passage to the upper Snake River. Overall, 22 dams were completed on the mainstem of the Snake and Columbia rivers by 1975 (Table 2). They blocked about 50% of the inland headwaters from access by anadromous fish.

Wherever dams were installed, their impoundments inundated the spawning areas used by anadromous fish and significantly delayed the seaward migrations of smolts (Raymond 1979). Eventually, about 783 km (486 mi) of lotic river environment were converted into lentic or semilentic reservoirs.

TABLE 2. Mainstem dams adversely affecting anadromous fish runs on the Columbia and Snake river systems and their initial year of service.

Columbia River	Year of initial service	Snake River	Year of initial service
Rock Island	1933	Swan Falls	1910
Bonneville	1938	Lower Salmon Falls	1910
Grand Coulee	1941	Bliss	1949
McNary	1953	C.J. Strike	1952
Chief Joseph	1955	Brownlee	1958
The Dalles	1957	Oxbow	1961
Priest Rapids	1959	Ice Harbor	1961
Rocky Reach	1961	Hells Canyon	1967
Wanapum	1963	Lower Monumental	1969
Wells	1967	Little Goose	1970
John Day	1968	Lower Granite	1975

Reservoir habitats favor an increase in numbers of resident predator fish such as northern squawfish (*Ptychocheilus oregonensis*), largemouth and smallmouth bass, and walleye, all of which may prey on juvenile salmonids (Raymond 1979). Delays in downstream migration of smolts from the interconnected reservoir system can also extend their residence time and hinder osmoregulation on their entry to seawater (Adams et al. 1975; Zaugg and McLain 1972).

Mortalities of adult upstream and juvenile downstream migrants have caused great concern since the 1940's. Adult passage facilities at downstream dams were often ineffective, and delays were sometimes accompanied by adult mortality (Beiningen and Ebel 1970; Liscom et al. 1977; Johnson et al. 1982). Fishway designs were improved to attract and pass returning adults. Subsequent research showed that juvenile fish suffered high mortalities from passage through turbines at each dam, from predation on stressed fish below dams, and from delayed passage through consecutive reservoirs (Collins 1976; Ebel and Raymond 1976; Ebel et al. 1979; Raymond 1979).

Agriculture and Irrigation

Over 10×10^6 ha are used for agriculture in the Columbia Basin. Impacts on fish and fisheries arise primarily from water withdrawal, soil erosion and sedimentation, and from leaching of animal wastes, fertilizers, and pesticides to streams.

Early irrigation systems were unscreened and they entrained juvenile fish into canals and ditches to die. Today, most diversion intakes are screened on streams used by anadromous fish, but withdrawal of water still lowers flows on some tributaries to critically low levels, reducing or eliminating salmonid production.

The semi-arid ranges of the interior Columbia Basin were overgrazed from the time of early settlement. Uncontrolled grazing contributed to erosion and siltation of tributary streams. Grazing also destroyed riparian vegetation, and caused increases in water temperature and organic pollution. Overgrazing in riparian areas along tributaries remains a problem. Fish production in ungrazed streams is from 2.4 to 5 times higher than in grazed streams (Platts 1981).

Logging

Effects of logging include blockage to and alteration of stream habitat, sedimentation, and degradation of water quality through application of fertilizers, herbicides, and pesticides (NPPC 1986). The result is reduced productivity of tributary streams for salmonids.

Logging probably had its greatest impact from 1880 to 1910, especially in the Willamette River drainage, and in southwestern Washington where over 100 splash dams were built to transport logs downstream. The South Fork of the Salmon River, Idaho, was severely damaged between 1952 and 1965 when spawning gravels became heavily silted.

Mining

Mining activities in the Columbia Basin began early, particularly for gold and silver, and were extensive in the mid-1880's. Mining districts were formed and worked on the Salmon, Boise, John Day, Powder, Coeur d'Alene, and Clark Fork rivers (NPPC 1986). Placer mining, often by dredges, displaced stream gravel, added sediment downstream, and eliminated salmonids from many productive areas in Oregon and Idaho. Lode mining degraded water quality by seepage from tailing ponds and mines, especially in Idaho.

Stream Channelization and Clearing

Stream channelization and clearing degraded and destroyed salmon habitat in many streams. Waterways were initially highways for transport of settlers and supplies. The advent and use of the automobile in mountains required that roads be placed along waterways. Boulders and woody debris were often cleared from streams, and this material was used to dike off sloughs and side channels to consolidate the main stream. The cleanup of debris in hundreds of streams during the late 1940's and early 1950's is now viewed as misguided effort.

Industrial Pollution

The discharge of untreated wastes from municipal and industrial sources into Columbia Basin streams accompanied population growth in the 20th century. Effluents from sewage treatment plants, pulp and paper mills, and aluminum plants produced much of the pollution. Runoff from urban nonpoint sources also increased pollution loads (NPPC 1986).

By the 1960's, pollution in the lower Willamette River became so severe that oxygen levels were critically low (0–3 ppm), juvenile migrants attempting to reach the Columbia River suffered losses, and adults attempting to enter the Willamette River were delayed (Fish and Wagner 1950). Plutonium production reactors in the Hanford Reach from 1944 to 1971 used once-through cooling and released radioactivity and heat. However, effluent monitoring and onsite studies showed no effects on fish or other aquatic biota from radioactivity, and minimal to no effects from heated water. More recently, sublethal concentrations of fluoride ($0.3-0.5$ mg$\cdot$L^{-1}) in effluents from an aluminum plant caused excessive delays of adult upstream migrants at John Day Dam (Damkaer and Dey 1985); fluoride discharges were reduced in 1983, and delays are no longer apparent.

Point-source discharges are not viewed as a serious problem in most of the Columbia River drainage today because the Clean Water Act of 1972 has legislated improved treatment of both industrial and municipal wastes, and point-source discharges are regulated by National Pollution Discharge Elimination System permits.

Smolt Passage Problems

Upriver stocks of salmon and steelhead in the Columbia River have been severely stressed because juveniles must pass eight or nine mainstem dams and reservoirs to reach the sea. Losses at each dam are substantial. From 1968 to 1975, when the four latest mainstem dams were completed on the Snake and Columbia rivers, average survival of juvenile spring chinook salmon passing from the upper Snake River to The Dalles Dam was reduced from 63 to

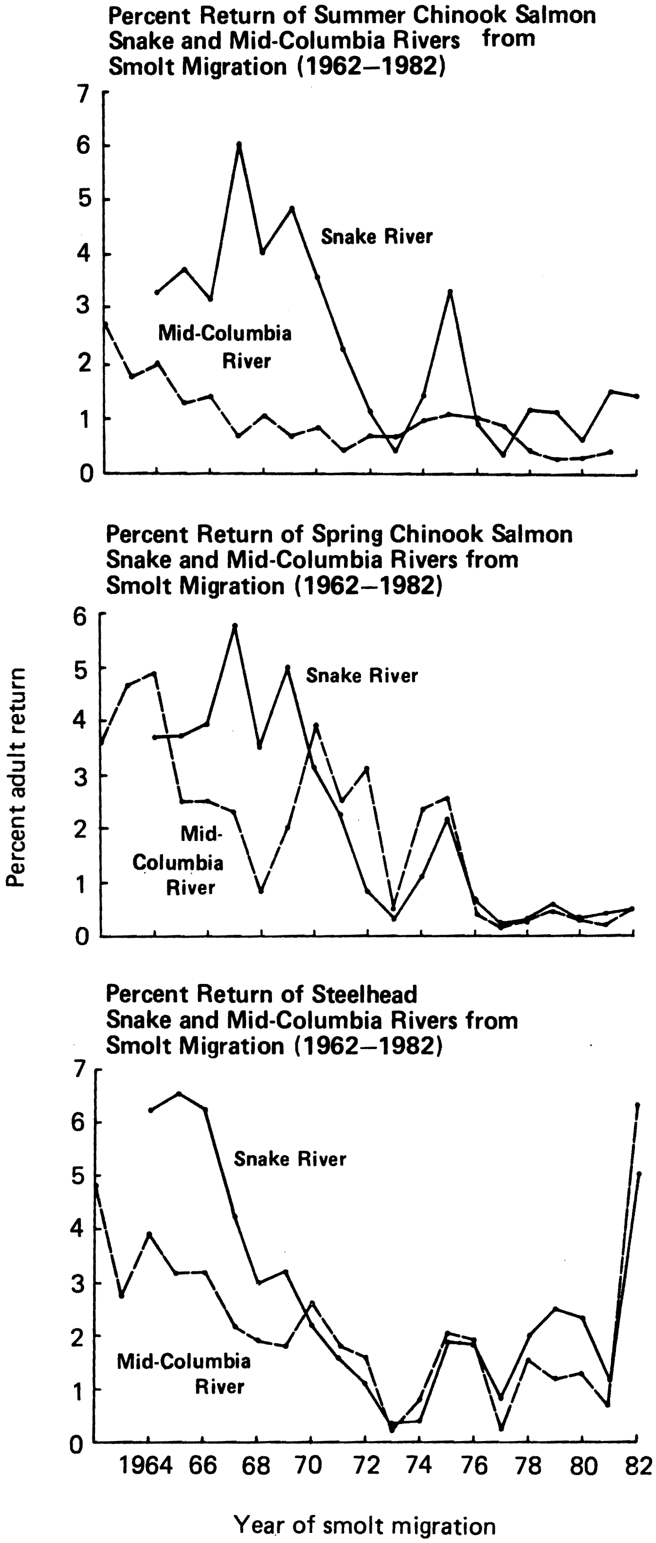

FIG. 4. Percentage return of chinook salmon and steelhead trout to the Snake River and mid-Columbia River dams based on smolt migrations during 1962 to 1982.

20 % (Raymond 1979).

In low flow years, most of the water is passed through turbines at dams, causing high mortalities of smolts from injury and, later, predation. Outmigrant losses range from 15 to 30 % at each dam, and cumulative losses during low water years are particularly severe (Ebel et al. 1979; NPPC 1986). During 1973 when flows were low, about 95 % of all juvenile salmon and steelhead emigrating from the Snake River were lost before they reached the Columbia River's estuary. By 1972, increased storage from the Mica and Arrow Lakes projects in Canada and increased turbine capacity of dams in the United States resulted in little or no spill at mainstem dams in average, as well as in low-flow years.

In high-flow years, when more water passes over spillways at dams, the river may entrain air in the plunge basin, leading to supersaturation and "gas bubble" disease among fish. During high-flow years from 1965 to 1975, mortalities ranged from 40 to 95 % of all outmigrants from the Snake River (Ebel 1971; Ebel and Raymond 1976). Losses of smolts from turbine passage and predation are minimal during high flows because most outmigrants pass with the spill and immediate mortalities are less than 3 % (Schoeneman et al. 1961). Thus, smolt losses at dams are usually lower in high-flow years than in low flow years.

Mortalities during smolt migration are reflected in low returns of spring and summer chinook salmon and steelhead to the Snake and mid-Columbia rivers (Fig. 4). Percentage returns declined between 1962 and 1974, when additional dams were constructed on the lower Snake River.

Actions taken to reduce smolt mortalities include: (1) installation of spillway deflectors (Fig. 5) at key dams, to reduce supersaturation of air in water; (2) installation of fingerling bypasses at dams, to direct smolts away from turbine intakes; (3) development of target flows, to provide more water during fish migrations; (4) implementation of annual spills at dams, to provide safe passage downriver; and (5) collection of smolts at upriver dams, for transport and release downstream below Bolleville Dam. In addition, hatchery production was increased to compensate for losses at dams.

In 1984, 90 % survival of outmigrants was set as a standard for each dam by the Northwest Power Planning Council. This standard can be met at most dams in most years without special spill. Yet cumulative mortality remains high today. Increasing smolt survival at each dam to 94 % in normal or high water years, and to 90 % in low-water years, would be a significant achievement.

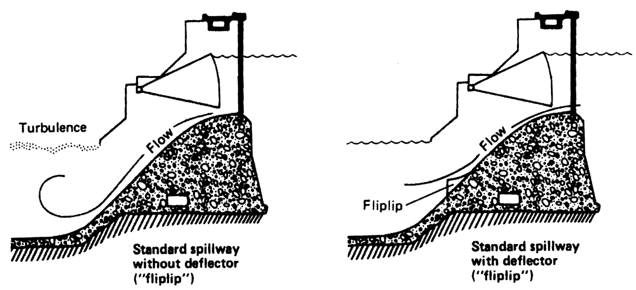

FIG. 5. Sketch of "Fliplip" deflector installed on spillways of Columbia River dams to reduce supersaturation of atmospheric gases.

Artificial Propagation

Compensation for losses of salmonids in the Columbia River system resulted in extensive rearing programs. By the late 1960's, hatchery production of fall chinook and coho salmon and steelhead far surpassed the remaining natural production. However, hatchery compensation is a two-edged sword. While releases supplement adult return runs, they also affect the survival of "wild runs." Large-scale production of hatchery fish on the lower Columbia River has been reported as detrimental to upriver runs of natural fish (NPPC 1986).

An estimated 395 million young salmonids weighing 3.0×10^6 kg (6.6×10^6 lb) were released in 1983 (GAIA Northwest Incorporated 1986). These fish were produced in 54 primary hatcheries or, including substations, 94 rearing facilities. Other hatcheries have begun operation since 1983. Thus, about 400 million anadromous fish are now stocked annually in the Columbia River system. The full potential of these hatcheries is near 1 billion smolts.

With such massive releases, hatchery salmonids now contribute substantially to catches of adult fish in the ocean and lower Columbia River. In 1977, about 75 % of the coho salmon caught in ocean sport fisheries off the Oregon coast, and 85 % of those caught off the Columbia River, came from hatcheries (Scarnecchia and Wagner 1979).

Young salmonids in hatcheries are not subject to high mortality in fresh water, as are naturally produced fish, because rearing conditions are controlled. Theoretically, hatchery stocks can withstand a greater harvest than natural stocks. While release of large numbers of fish from hatcheries as compensation for lost natural production did slow the decline of many runs, they also encouraged an increase in total harvest. Regulating mixed stocks for maximum allowable catches of hatchery fish caused the less productive natural stocks to erode (Lichatowich and McIntyre 1986). Further, it increased the dependence of many stocks on costly artificial propagation programs (PMFC 1982).

Institutional Arrangements

Until the early 1900's, anadromous fish in the Columbia River were harvested in estuaries and rivers as the adults returned to spawn. Initial effort to halt declines in the various runs was simply to restrict the commercial catch. Increasingly severe restrictions on inside fisheries failed to halt the downward trend. Analysis of the 1938 return runs led to the conclusions that the declines were caused primarily by overharvest (only 17 % of the June–July chinook salmon run escaped to spawn), and that catch restrictions were limited by political infighting and, therefore, were largely ineffective (Rich 1941).

In subsequent years, the ocean fisheries expanded and more was learned about the behavior and migration of various species and stocks. Evidence now shows that protecting anadromous fish of the Columbia River requires regulation of catches in both fresh and salt water (Fig. 6). Early regulation of the ocean fishery was confined to seasonal catch restrictions, which were enforced by individual states with jurisdiction extending only 5.6 km (3 nmi) offshore. Federal jurisdiction was extended from 5.6 to 22.2 km (3 to 12 nmi) by passage of the Bartlett Act in 1966, and to 370.6 km (200 nmi) by the Fishery Conservation and Management Act in 1974. Further, early regulations were not always uniform among states and, generally, were not designed to achieve specific stock-by-stock escapement goals. Concepts of scientific fishery management did not begin to emerge until the 1940s.

In 1938, Congress passed the Mitchell Act authorizing

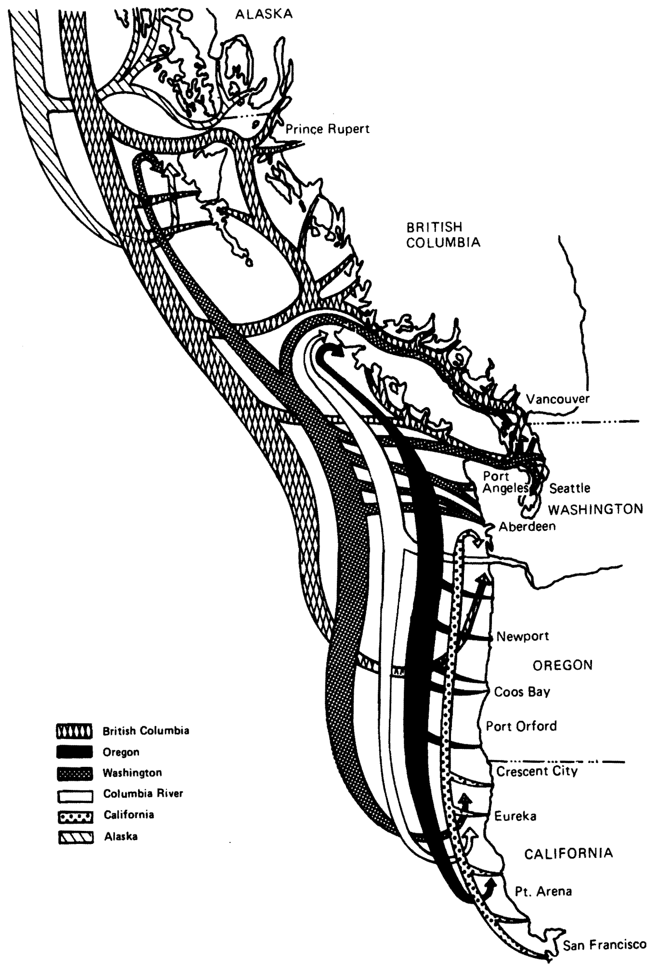

FIG. 6. General migration patterns of chinook salmon in northeastern Pacific Ocean. Migration patterns of coho salmon are similar.

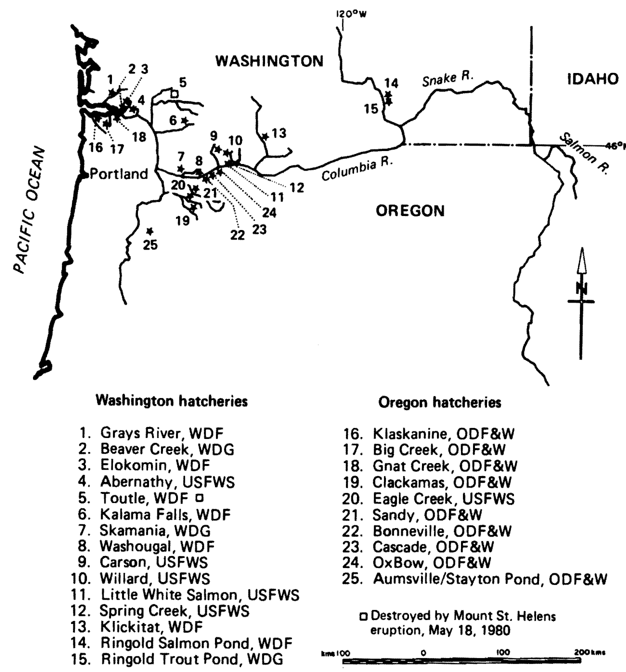

FIG. 7. Hatcheries funded under the Columbia River Fisheries Development program.

artificial propagation to compensate for destruction of habitat by hydroelectric development and other environmental changes. The Act was amended in 1946 to support state participation in stream improvement (fish passage over natural barriers, screening of irrigation diversions, and opening of streams blocked by debris), and in research to improve the quality of hatchery fish. Formalized as the Columbia River Fisheries Development Program, about 80 % of the available funds are now used to support 21 hatcheries and three rearing ponds (Fig. 7), with an annual production of about 100 million juvenile salmonids (Table 3).

Conflicts with various Indian tribes over regulation of tribal fisheries by states peaked in the early 1970's. These conflicts resulted in a 1979 ruling by the Supreme Court (the Boldt decision) that an 1855 treaty guaranteed 20 tribes the right to catch salmon and steelhead in their usual and accustomed places, and that the tribes were entitled to 50 % of the harvestable fish. Today, the treaty tribes participate in decisions affecting management of the resource through the Northwest Indian Fisheries Commission, the Columbia River Intertribal Fish Commission, and other liaison groups.

The federal government assumed management authority in 1974 with passage of the Fishery Conservation and Management Act. This Act established exclusive U.S. fishery authority over all salmon (and most other species) in the ocean within a 5.6–370.6 km (3–200 nmi) fishery conservation zone, except in territorial waters of other countries. Two regional councils for management were established under the Act: the Pacific Fisheries Management Council (PFMC) has jurisdiction off the coasts of California, Oregon, and Washington; the North Pacific Fishery Management Council (NPFMC) has jurisdiction off the coast of Alaska (Fig. 8).

The U.S./Canada salmon treaty, ratified in 1985, represented another milestone. It provided for regulating ocean fisheries to ensure meeting Indian treaty obligations, equitably distributing the catch between ocean and freshwater fisheries, and achieving spawning escapement goals (PMFC 1982).

With passage of the Water Resources Development Act of 1976, the Lower Snake River Fish and Wildlife Compensation Plan (SRCP) was authorized to compensate for losses of fish caused by hydroelectric projects on the Snake River. The SRCP called for hatchery releases sufficient to produce returns to the Snake River of 18 300 adult fall chinook salmon, 58 700 adult spring and summer chinook salmon, and 55 100 adult steelhead. Although such returns have not resulted to date, significant supplementation is occurring. The SRCP also called for release of 93 000 pounds of trout annually to compensate for loss of sport fish production in Washington and Idaho streams.

The Pacific Northwest Electric Power Planning and Conservation Act (NPCA) of 1980 and its accompanying Fish

TABLE 3. Numbers of salmonids released from hatcheries funded under the Columbia River Development Program from 1960 to 1984 (from Delarm and Wold 1985). All data × 10^6.

Year	Fall chinook salmon	Spring chinook salmon	Coho salmon	Steelhead trout	Totals
1960	89.1	1.8	6.4	1.0	98.3
1961	46.6	0.8	14.2	0.9	62.5
1962	55.8	1.7	12.9	1.6	72.0
1963	58.8	2.4	19.6	1.4	82.2
1964	65.5	7.6	16.5	1.7	91.3
1965	56.2	3.0	17.9	1.9	79.0
1966	54.9	3.8	19.7	2.5	80.9
1967	55.1	5.5	20.2	2.3	83.1
1968	55.5	3.8	15.7	3.0	78.0
1969	57.9	3.5	18.6	2.3	82.3
1970	62.2	2.6	17.4	2.9	85.1
1971	63.3	3.8	21.3	2.4	90.8
1972	67.1	3.6	23.9	2.5	97.1
1973	70.4	4.8	20.9	2.5	98.6
1974	65.5	4.4	20.2	2.3	92.4
1975	67.3	5.2	21.1	1.9	95.5
1976	84.0	5.9	22.2	2.1	114.2
1977	95.0	5.1	26.3	2.2	128.6
1978	89.3	5.5[a]	26.3	2.4	123.5
1979	89.1	7.5[a]	21.1	2.4	120.1
1980	80.1	7.2[a]	20.8	2.2	110.3
1981	73.3	7.6	19.2	2.3	102.4
1982	78.6	7.3	17.4	2.1	105.4
1983	74.5	6.9	21.7	2.1	105.2
1984	72.4	8.7	22.3	3.3	106.7

[a] Includes a small number of summer chinook salmon.

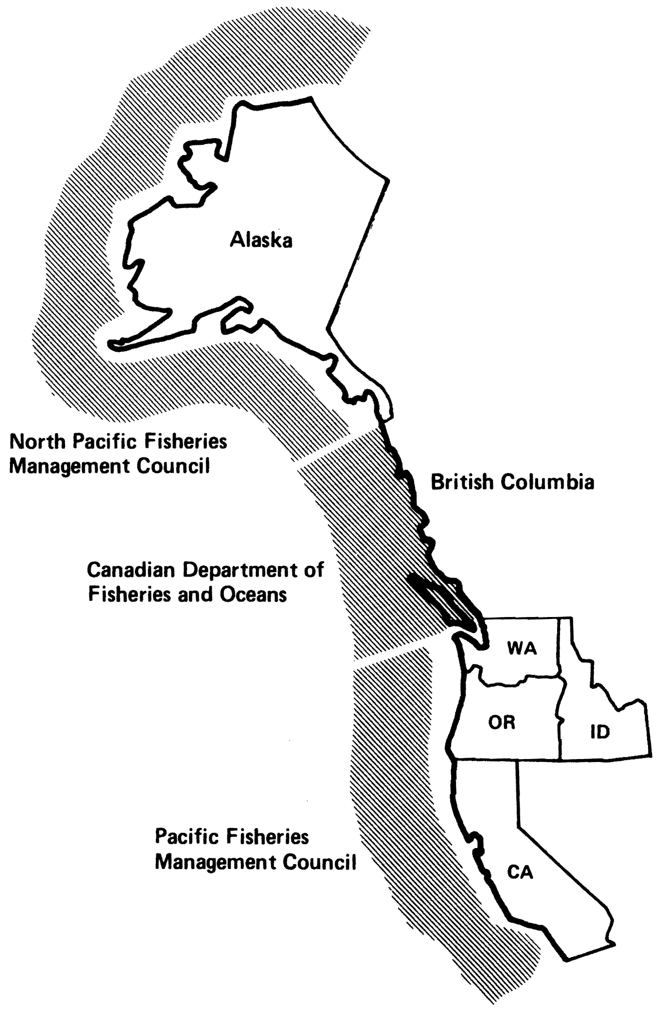

FIG. 8. Jurisdiction of U.S. and Canadian marine regulatory agencies.

and Wildlife Program (currently funded at about $30 million annually) represented another milestone, particularly in improving degraded habitat in the Columbia River. The Program includes a water budget that sets aside $5724 \times 10^6 \cdot m^3$ of water each year to increase spills at dams from April 15 to June 15. Additionally, spill plans are drafted and implemented by fishery and tribal personnel working with public power utilities, the Corps of Engineers, and the Bonneville Power Administration. The intent is to reduce mortality of outmigrating smolts in turbines.

Public utilities and the Corps of Engineers have made substantial progress in compensating for salmon and steelhead losses at their dams on the Columbia River. Besides funding smolt production at hatcheries, they have spent millions of dollars annually to improve upstream and downstream passage of fish, and to provide adequate flows for fall chinook salmon spawning in the Hanford Reach below Priest Rapids Dam.

The results of these efforts are encouraging. Counts at Bonneville Dam since 1960 are listed in Table 4. About 440 000 salmonids were caught commercially in 1984. This was the highest catch since 1976 and may be attributed to a substantial increase in the size of runs.

Recent escapements are also encouraging. Several runs show an upward trend since 1980. Record returns of steelhead and fall chinook salmon in 1984 and 1985 reflect increased production of fall chinook salmon in the mid-Columbia River and benefits from improved passage of smolts. Upriver runs of summer chinook and sockeye salmon have also increased — this is especially evident from counts recorded in 1985.

Needs and Opportunities

The reasons that early efforts to compensate for declining salmon runs in the Columbia River were ineffective or failed include the unprecedented rate and magnitude of hydroelectric development on the Columbia River, and the limited knowledge and technology applicable to anadromous fish passage at the time. Many hatchery operations (e.g., hatcheries built to mitigate habitat loss from the Grand Coulee project) were conceived with inadequate background data as provisional experimental programs, subject to ongoing evaluation and updating, a proviso rarely done.

There was also the matter of priorities. Once dams were finished and operating, enthusiasm was often lost by construction agencies to see, and Congress to provide, compensation that was implied or promised when political support was sought for project appropriations. In addition, belated compensation programs were subjected to far more rigorous economic scrutiny than the projects that created the need (Chaney 1978). Nearly 15 years passed between completion by the Corps of Engineers of the first dam on the lower Snake River and the first compensation hatchery.

Numerous obstacles must still be faced to effectively manage anadromous salmonids of the Columbia River. New problems are likely to appear as greater insight is gained.

TABLE 4. Numbers of salmonids counted over Bonneville Dam on the lower Columbia River from 1960 to 1985.[a]

Year	Spring chinook salmon	Summer chinook salmon	Fall chinook salmon	Steelhead trout	Sockeye salmon	Coho salmon
1960	69 595	85 170	101 282	113 676	59 713	3 268
1961	98 695	66 461	119 916	139 719	17 111	3 456
1962	89 635	77 310	118 039	164 025	28 179	14 788
1963	75 473	64 013	139 079	129 418	60 319	12 658
1964	91 425	80 531	172 463	117 252	99 856	53 602
1965	84 261	75 974	157 685	166 453	55 125	76 032
1966	112 669	71 997	155 445	143 661	156 661	71 891
1967	84 935	95 659	185 643	121 872	144 158	96 488
1968	99 187	82 919	159 247	106 974	108 207	63 488
1969	173 566	102 153	231 838	140 782	59 636	49 378
1970	110 976	65 510	208 902	113 510	70 762	80 166
1971	125 517	77 911	202 274	193 966	87 447	75 989
1972	186 140	70 830	137 486	185 886	56 323	65 932
1973	142 148	45 360	211 127	157 823	58 979	54 609
1974	134 535	45 896	186 328	137 054	43 837	60 955
1975	104 104	44 351	277 111	85 540	58 212	58 307
1976	113 446	69 013	325 312	124 177	43 611	53 150
1977	119 508	41 023	206 126	193 437	99 829	19 408
1978	149 863	44 323	200 404	104 431	18 436	52 590
1979	51 462	34 217	190 613	113 979	52 628	45 328
1980	60 987	31 065	153 466	129 254	58 882	22 052
1981	65 009	26 929	193 712	159 270	56 037	30 510
1982	76 044	26 614	220 151	157 640	50 219	73 832
1983	56 838	23 458	164 180	213 779	100 527	15 176
1984	51 142	28 448	243 756	315 795	152 540	29 332
1985	90 964	29 353	334 436	326 194	165 928	55 529

[a] Dam counts indicate only escapement to the river, not total run size. Total run includes commercial and sport catches, and escapements to tributary streams below Bonneville Dam. Counts at dams today are further reduced by the Tribal fishery and a limited sport fishery above Bonneville Dam.

First, reducing smolt mortalities at dams remains an overwhelming need. Substantial progress has been made on developing and installing turbine screening and bypass systems at Columbia River dams. Yet technology still cannot reduce losses at each dam to less than 5 % and few dams have yet attained such efficiency. Collection of seaward migrants in the Snake River at Lower Granite and Little Goose dams and at McNary Dam on the Columbia River, and barging or trucking them downstream, has produced favorable results. Steelhead and coho and fall chinook salmon have definitely benefited. The effectiveness of collection and transportation systems apparently varies with species, just as different abiotic factors influence losses at each dam.

Second, judicious allocation of spill over dams during seaward migration periods is required where effective turbine screen and bypass systems have not been installed. Not enough water is available in the mainstem of the Columbia and lower Snake rivers during years of low and average runoff for both hydroelectric power and downstream passage. The Water Budget of the NPPA Fish and Wildlife Program offers some improvement. Use of spill to reduce turbine mortalities may be an interim measure. Water for flushing smolts downstream and over dams will always be contested by other water users, particularly by power producers. The conflict emphasizes the need for adequate turbine screen and bypass systems.

Third, the problem of integrating hatchery releases and wild production without deleterious effects on wild stocks must be addressed. This includes density-dependent survival in fresh and salt water associated with large releases of smolts from hatcheries, and reduced survival of wild salmonids in tributaries laced with hatchery outplants to supplement natural spawning (Lichatowich and McIntyre 1986).

Fourth, disease continues to plague some hatchery stocks. Returns of upriver spring chinook salmon to federal hatcheries remain low. The presence of bacterial kidney disease (BKD) in hatchery stocks of spring chinook salmon that now contribute 70–80 % of the seaward migration may cause poor survival (Banner et al. 1982; Fryer 1984). Juvenile spring chinook salmon are overwintered in hatcheries and released in early spring. Major BKD outbreaks occur near release time and may be induced by approaching smoltification. Could losses be reduced by new vaccines or by altering hatchery practices? Perhaps releases to impoundments in the fall for overwinter conditioning would increase survival.

Fifth, relationships between resident and migratory species need to be examined. Creation of impoundments and introduction of exotic fish has altered the composition and abundance of fish populations. Predation on salmonid outmigrants may be extensive, and other cause-and-effect relationships such as competition and disease transmission may exist.

Sixth, while pollution is not a major problem, information on current levels of contaminants in water, sediments, and fish tissue is incomplete. Salmonids in some areas now carry low burdens of polychlorinated biphenyls and chlorinated hydrocarbons, presumably derived from past industrial releases and return of contaminated irrigation water.

Seventh, mixed stock fisheries must be effectively regulated to prevent overharvest of wild stocks. This requires adequate data on the ocean distribution of stocks in the offshore fishery, the relative size of stocks available for harvest, and the response of stocks to oceanic conditions. Some data are available for hatchery fish from marking programs, but information on wild fish is meager. New techniques in stock identification (scale and parasite analysis, coded wire tags, genetic variant data) will help.

Eighth, efforts to increase natural production throughout the Columbia River system may be countered by construction of small hydropower dams on tributaries. The cumulative impact of hundreds of proposed projects on instream smolt production could be severe, depending on which projects are authorized.

According to one's philosophy, the resource base of salmon and steelhead in the Columbia River is either half empty (and declining) or half full (and increasing). The current program is not without critique (Anonymous 1986). However, the apparent success of recent management actions, which involve the cooperation of many agencies and governments, is encouraging. If current effort is continued, annual production of anadromous fish in the Columbia River system may increase to a level consistent with ecosystem changes and competing societal uses.

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