CHEHALIS RIVER BASIN FISHERY RESOURCES: STATUS, TRENDS, AND RESTORATION

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EXECUTIVE SUMMARY

The Chehalis River Basin Fishery Resources Study and Restoration Act (Public Law 101-452) requires the Director of the Fish and Wildlife Service (FWS) to "undertake a comprehensive study of the fishery resources and habitats of the Chehalis River Basin of Washington State, develop goals, recommend long- and short-term actions to maximize the restoration and conservation of those fishery resources, and report his findings to Congress."

The present report reviews existing information, sets goals, and presents a number of restoration recommendations. A second report, based on an ongoing survey of fishery habitat and scheduled for completion in 1993, will describe actual habitat conditions and further guide restoration. This report focuses on anadromous salmonids since they are clearly the most important fishery resources of the Chehalis Basin.

To guide activities under the Act, a steering committee composed of representatives of all relevant state agencies, Indian Tribes, and the public was formed in 1990. The committee recognized that a large amount of information about Chehalis Basin fishery resources already existed but that it needed to be gathered together in one report. The present report is the result of that task.

SUMMARY OF FINDINGS

Reviews of existing information on resource history, run status, and current habitat problems reveal that:

(1) Inner Grays Harbor water quality appears to have contributed to poor coho (and probably chinook and steelhead) smolt survival at least until 1989. Significant efforts to improve water quality have been taken. Results of clean-up will become known in a few more years. Further study of pollution may be necessary but can be delayed pending the outcome of ongoing survival evaluation.

(2) Wild coho and chum salmon populations have fallen well below levels that historically supported high catches.

(3) Chinook salmon and steelhead do not consistently use all potential habitat.

(4) Upper Chehalis River water quality particularly threatens adult spring and fall chinook, and reduces coho and steelhead rearing habitat.

(5) Dams and other barriers, logging, road building, agriculture, and urbanization have degraded salmon and steelhead habitat.

While natural salmon and steelhead production is apparently less than optimal in the Chehalis Basin, there is every indication that, with careful planning and implementation, production can be improved. The Basin contains several thousand miles of stream habitat, much of which is in relatively good condition. The lack of large-scale, main stem dams, as found on the Columbia, also increases the prospects for successful restoration.

Healthy fisheries are an important component of the Basin's economic infrastructure. Rebuilding salmon and steelhead habitat can help rebuild the Basin's economic vitality. When depressed runs are restored, harvest constraints can be eased, allowing harvest of not only the restored runs, but intermingled, healthy runs as well. Moreover, good recreational fishing opportunity can attract new industry to an area. The recommendations proposed in this report will create jobs for local workers both during restoration and after healthy fish populations are rebuilt.

PROPOSED FISHERY RESTORATION GOAL

The findings have led to formulating a general goal:

> **"to optimize natural salmon and steelhead production while maintaining the existing genetic adaptation of wild spawners and allowing the highest compatible level of hatchery production".**

Natural production will be restored when the total estimated wild catches consistently lie within the range of historical estimates, and when wild escapement goals are consistently met. This means:

(1) Expanding spring chinook salmon wild production to its full potential range.

(2) Sustaining the recent increase in Chehalis River System fall chinook salmon by improving water quality throughout the Chehalis River System.

(3) Doubling Chehalis River System coho salmon smolt-to-adult survival, compared to the 1989 level, so that Chehalis River System smolt survival equals Humptulips River System smolt survival.

(4) Increasing chum salmon run sizes to historical levels.

(5) Ensuring that wild winter steelhead fully and consistently use the spawning habitat in each available Chehalis River Basin sub-basin.

(6) Evaluating existing wild summer steelhead populations in Chehalis Basin tributaries.

RESTORATION CRITERIA

Habitat Condition

Habitat restoration projects in the Chehalis watershed may not produce results unless recent effluent treatment upgrades at the two inner Grays Harbor pulp mills result in significant improvement of survival. If survival has improved sufficiently, then habitat restoration throughout the basin should be successful, and projects using promising and cost-effective techniques should be initiated to begin restoration. If survival has not improved, further efforts should be directed to solving the poor inner Harbor survival problems before extensive watershed habitat restoration proceeds. Since it will take at least two more years before results of tagging studies can confirm clean-up effectiveness, preliminary habitat restoration projects should be started and evaluated. Once the inner Harbor water quality allows reasonable smolt survival, proven habitat restoration projects can begin throughout the Basin on a larger scale. Selection of habitat restoration projects will be guided by the ongoing habitat survey.

Hatchery Role

Hatchery production supports a large share of the catch in several fisheries. However, once habitat problems have been corrected, the hatchery role in fishery restoration should be to augment, rather than replace, natural production. Hatcheries may produce fish poorly adapted for wild survival and can jeopardize the health and sustainability of wild runs, so programs must be developed cautiously. Ongoing State and Tribal processes should continue to carefully evaluate all hatchery programs to help understand how they are contributing to fisheries and whether there is negative interaction with wild stocks. Artificial enhancement can and should be utilized wherever it will not harm the integrity of wild stocks. However, emphasizing hatchery production to the detriment of efforts to restore naturally reproducing populations is not an acceptable policy option.

Public and Interagency Involvement

Public and interagency cooperation is vital to the success of restoration. This requires the active participation of the tribes and agencies named in the Chehalis Act as the Restoration Plan is implemented. These key entities will identify and explore avenues of cooperation with all interested private organizations and agencies not already involved. The public was invited to a Basin-wide fisheries conference in the fall of 1992 where study findings were presented and suggestions for restoration priorities sought.

The FWS recommends that the Chehalis Basin Steering Committee, formed under the Chehalis Basin Fishery Restoration Study Act, be continued to provide policy guidance to the restoration proposed in this report. They will guide restoration to ensure each project would restore fish, be cost-effective, meet cost-share requirements, and contain appropriate evaluation components.

It is also critical that all <u>existing</u> programs designed to protect, restore, and enhance fisheries and their habitat continue to be fully supported and funded.

RESTORATION OBJECTIVES

The overall life-span of the restoration project is 20 years, assuming full funding is made available. Some tasks can be completed in one or several years while others will be accomplished gradually over the 20 years. Since all restoration projects will at least initially be evaluated for fish restoration effectiveness, these recommendations will need to be revised over time. Projects found to be ineffective will not be further pursued. The costs of these evaluations has been included in the project costs estimated below.

The following objectives are proposed:

OBJECTIVE 1: Restore or improve natural spawning or rearing habitat.

OBJECTIVE 2: Improve water quality to meet State standards year-round in the middle and upper Chehalis River System.

OBJECTIVE 3: Ensure that environmental conditions causing poor smolt survival in inner Grays Harbor are remedied.

OBJECTIVE 4: Ensure that storage dam operation and surface water withdrawal is compatible with fish production.

OBJECTIVE 5: Extend the range of salmon and steelhead within the Basin to achieve optimum habitat use.

OBJECTIVE 6: Optimize opportunities for artificial enhancement without jeopardizing wild stocks.

OBJECTIVE 7: Use fisheries harvest management techniques and increased enforcement to increase run sizes.

OBJECTIVE 8: Increase public awareness of the values of fisheries to the Chehalis Basin.

FUNDING NEEDS

Some restoration has occurred and will continue under existing federal, state, local, and volunteer programs. The proposed habitat restoration projects complement existing programs but should not replace them.

Since it is important that restoration techniques be demonstrated to be effective before they are fully implemented, it is recommended that restoration be funded gradually over 20 years. After careful review of the size and scope of all tasks necessary for full restoration, it is recommended that a total of $1 million be committed to Chehalis restoration from interested agencies in each of the 20 years. This level of funding is expected to restore significant fish populations, ultimately stimulating the economic recovery of the Chehalis Basin. The Fish and Wildlife Service is not prepared at this time to request additional funds for its share of this work. However, funds may become available by reprogramming from lower priority activities or through other sources.

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LIST OF ACRONYMS AND ABBREVIATIONS

BOD	Biological Oxygen Demand
BPA	Bonneville Power Administration
BRW	Black River Watch
CBFTF	Chehalis Basin Fishery Task Force
CD	Conservation District
cfs	Cubic Feet per Second
CRC	Chehalis River Council
CRTAB*	Chehalis River Technical Advisory Board
CRPMP	Coordinated Resource Production and Management Plan
DO	dissolved oxygen
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
FRI	Fishery Research Institute of University of Washington
FWE	Fish and Wildlife Enhancement Office of FWS
FWS	U.S. Fish and Wildlife Service
GHRPC	Grays Harbor Regional Planning Commission
GHCD	Grays Harbor Conservation District
GIS	Geographical Information System
IFIM	Instream Flow Incremental Method
LCCD	Lewis County Conservation District
LCWQB*	Lower Chehalis Water Quality Board
LLTK	Long Live the Kings

*Note: the official name now appears as "Chehalis River Technical Advisory Board" in the Lower Chehalis River Basin Water Quality Management Study

List of acronyms and abbreviations, continued.

mgd	million gallons per day
MLLW	Mean Lower Low Water
NMFS	National Marine Fisheries Service
NPDES	National Pollution Discharge Elimination System
OFM	Washington Office of Financial Management
ONF	Olympic National Forest
OPIN	Olympic Peninsula Information Network
PCB	Polychlorinated Biphenyl
PMFC	Pacific Marine Fisheries Council
ppb	parts per billion
PP&L	Pacific Power and Light
ppm	parts per million
ppt	parts per trillion
PSC	Pacific Salmon Commission
PSMFC	Pacific States Marine Fisheries Commission
QFiD	Quinault Fisheries Division of the Quinault Indian Nation
RM	River mile
SCS	U.S. Soil Conservation Service
TCCD	Thurston County Conservation District
TCDD	Tetrachloro Dibenzodioxin
TCDF	Tetrachloro Dibenzofuran
TFW	Timber, Fish, and Wildlife Agreement
TMDL	Total Maximum Daily Load (of permissible pollution)
TSS	Total suspended solids
TU	Trout Unlimited

List of acronyms and abbreviations, continued.

USACE	U.S. Army Corps of Engineers
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WDA	Washington Department of Agriculture
WDCD	Washington Department of Community Development
WDOE	Washington Department of Ecology
WDF	Washington Department of Fisheries
WDG	Washington Department of Game, now WDW
WDNR	Washington Department of Natural Resources
WDW	Washington Department of Wildlife, formerly WDG
WLA	Waste Load Allocation
WWFRO	Western Washington Fishery Resource Office of the FWS
WPPSS	Washington Public Power Supply System

Chapter 1: DESCRIPTION OF THE BASIN

The Chehalis River Basin, as defined in the Act, includes all the rivers and streams entering Grays Harbor and the land they drain (Figure 1), plus the waters of Grays Harbor itself. The Basin is the second largest in the State of Washington, the Columbia being the only one larger, and includes all of Grays Harbor County, most of Lewis County, parts of Mason and Thurston Counties, and small parts of Pacific and Wahkiakum Counties. The Chehalis Basin includes about 27,000 acres of saltwater in Grays Harbor itself (SCS 1975) and about 3,353 stream miles (Phinney *et al.* 1975). These waters provide a complex and diverse ecosystem with spawning and rearing areas that support several economically valuable species of anadromous fish (primarily salmon, steelhead, and sea-run cutthroat trout), whose restoration is the subject of this report.

PHYSICAL DESCRIPTION

The Chehalis River originates in the Willapa Hills in southwest Washington and flows into the Pacific Ocean via Grays Harbor. The main Willapa Hills tributaries of fishery interest are Elk Creek, which enters near the town of Doty, and the South Fork Chehalis, which enters near the town of Adna (Figure 2).

The river then flows east from the Willapa Hills into the Puget Trough, the lowland separating the Willapa Hills from the southern Cascades. At that point, the river flows north and receives two very important fish-bearing tributaries from the Cascade foothills. The Newaukum River enters near the town of Chehalis, and the Skookumchuck River joins the Chehalis River near Centralia (Figure 2).

From that point, the Chehalis Valley widens and turns to the northwest, where the Black River drains the southern Puget Lowlands, joining the Chehalis east of the Black Hills on the Chehalis Indian Reservation. Cloquallum Creek enters west of the Black Hills, near the town of Elma.

The river then turns to the west and drains the southern flank of the Olympic Range (Figure 2). The principal fish-producing streams of this region are the Satsop, Wynoochee, Wishkah, Hoquiam, and Humptulips Rivers. The Satsop enters the Chehalis River near the town of Satsop, and is the last major tributary upstream of tidal influence. The Wynoochee, Wishkah, and Hoquiam enter successively downstream at the towns of Montesano, Aberdeen, and Hoquiam. Near the Wishkah, the Chehalis widens into Grays Harbor, which is approximately 15 miles long and 13 miles wide.

The Humptulips River also drains the southern Olympics but, unlike the Chehalis tributaries, the Humptulips independently enters the north side of Grays Harbor. On the southern side of Grays Harbor, two small rivers, the Elk and the Johns, drain from the northern Willapa Hills. Grays Harbor joins the Pacific Ocean through a narrow channel north of the fishing town of Westport.

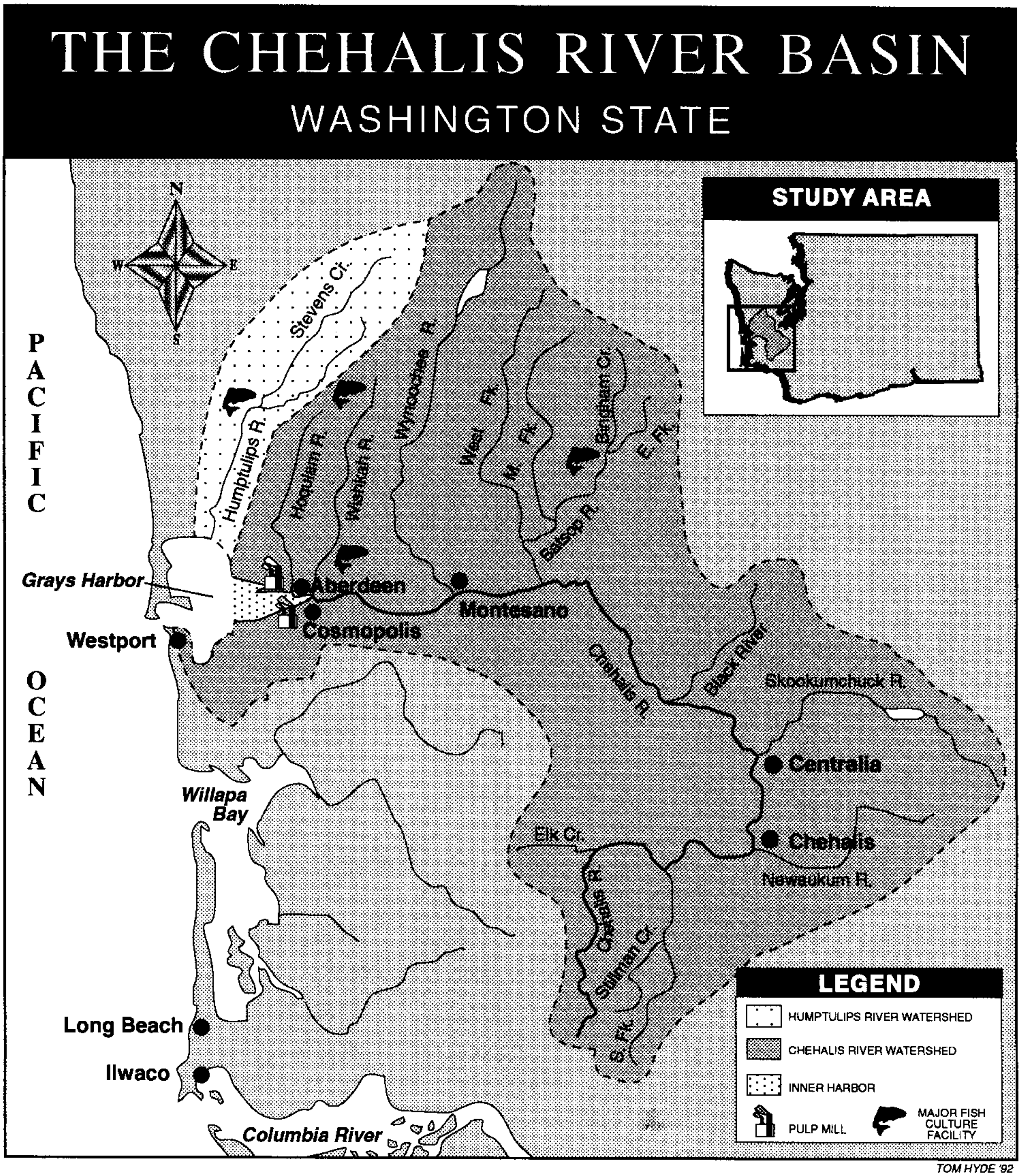

Figure 1. Location of Chehalis Basin in western Washington.

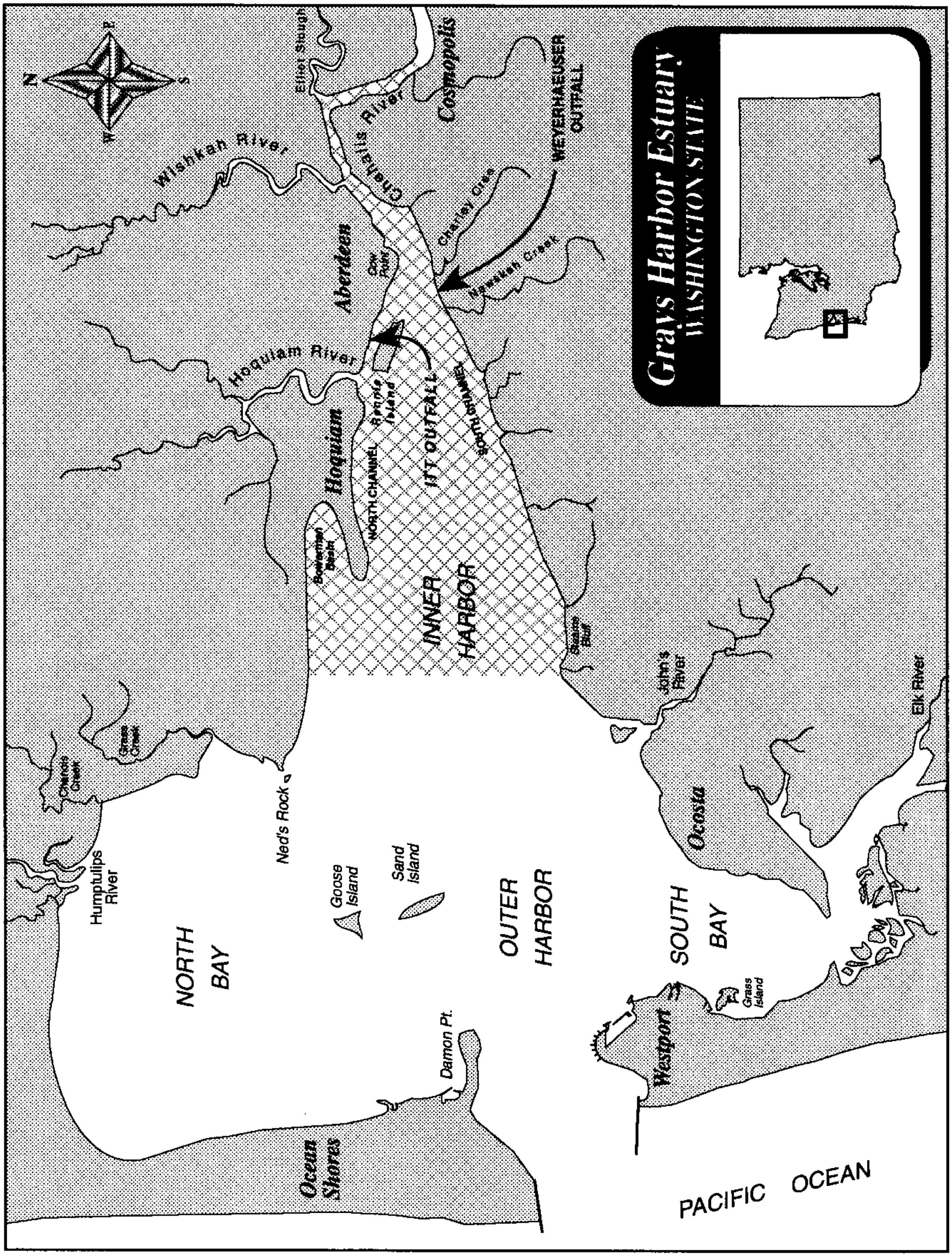

Figure 2.   Grays Harbor estuary.

For habitat management, it is convenient to divide the Basin into three parts: Grays Harbor, including all the tidal waters bearing that name, the Humptulips River System, and the Chehalis River System (Figure 1).

The distinction of inner from outer Grays Harbor (Figure 2) is useful because the inner Harbor has suffered more water pollution than the outer Harbor, and because Chehalis System fish must migrate through the inner Harbor whereas Humptulips System fish pass only through the outer Harbor (Figure 2).

HYDROGRAPHIC DESCRIPTION

River system	Area drained (square miles)	Streamflow (cfs)		
		Maximum	Mean annual	Minimum
Chehalis at Porter	1,294	34,600	4,262	164
Satsop	299	46,600	1,968	166
Humptulips	130	33,000	1,320	32
Wynoochee	179	24,500	1,275	23
Newaukum	155	7,400	506	12
Cloquallum Creek	65	3,650	375	63
Wishkah	58	7,400	A	33
Skookumchuck	62	6,710	247	16
Hoquiam	A	A	A	6
Black	61	1,700	162	5

A Not available.

Table 1. Relative size and stream flows of major tributaries to the Chehalis Basin (Mahlum 1976).

Annual rainfall varies from 40 inches in Centralia to 220 inches in the southern Olympics (Harper, in prep.); about 85 percent falling between October and April. Peak streamflows usually occur between November and March. After April, flow gradually subsides to late August or early September lows (Figure 3).

Mean annual freshwater flow into Grays Harbor has not been directly measured but is estimated at 11,208 cfs (Mahlum 1976). Table 1 illustrates the relative sizes of the Chehalis River near Porter and other significant tributaries based on streamflow data.

Rainfall, not snow melt, almost exclusively drives the annual rise and fall of streamflow throughout the Basin.

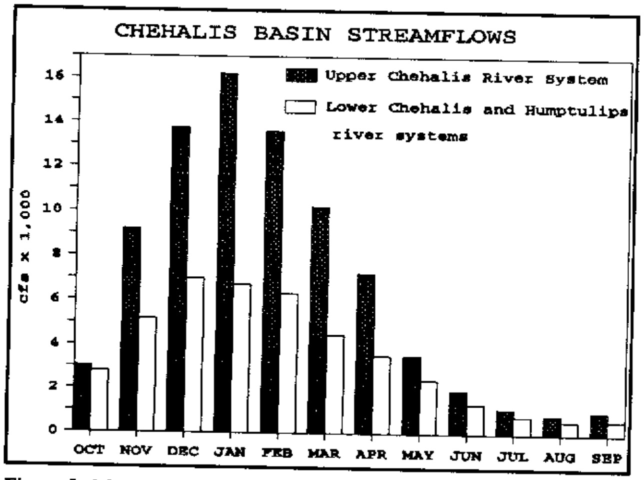

Figure 3. Mean monthly streamflows in the Chehalis Basin.

ECONOMIC AND SOCIAL DESCRIPTION

The Chehalis Basin is generally rural. The primary industries are forest products, followed by agriculture, tourism, and fishing. The area has higher unemployment than the state as a whole due primarily to increasing automation in the wood products industry and declining timber production (GHRPC 1992). Its inhabitants urgently seek economic diversification in the face of recent declines in availability of old growth timber from federal lands, primarily to the north of the Basin; old growth timber had until recently provided significant economic value in the Basin. Fishery development is seen as part of general tourism promotion in Grays Harbor County (Larry Wilder, Grays Harbor Tourism Council, pers. comm.).

Demographics

The Basin's population of about 117,000 has remained steady over the last ten years (Table 2). The largest incorporated area is the Aberdeen-Cosmopolis-Hoquiam complex. This area lost about eight percent of its population probably due to timber industry declines and cessation of construction at the Satsop nuclear plants. Small timber-dependent towns close to Aberdeen, such as Montesano and Elma, have similarly declined (OFM 1991).

The next largest concentration of population is in Centralia and Chehalis. This area has grown slightly, probably reflecting the residential sprawl from Olympia. The only other rapidly growing community is Ocean Shores, which is residential but depends largely on recreation.

About half of the Basin residents live in unincorporated areas (Table 2), primarily in Lewis and Thurston Counties. This population has grown rapidly, due to suburban expansion south from Olympia, but the trend is slowing. For example, from 1970 to 1980 the Black River watershed population doubled, but from then to 1990 it grew only 37 percent (Palmer, in prep.).

Category	1990 population	Percent of total	Change since 1980
Total	116,970	100.0	+1.1
Unincorporated	56,488[A]	48.3	+4.7
Incorporated	60,482	51.7	-2.1
Unincorporated[A]			
Lewis County	29,027	51.4	+8.2
Thurston County	24,603	43.6	+14.6
Grays Harbor County	25,858	5.0	-0.1
Incorporated			
Aberdeen-Cosmopolis-Hoquiam	27,615	45.7	-8.1
Centralia-Chehalis	18,480	30.6	+4.7
Montesano	3,270	5.4	-10.7
Elma	2,420	4.0	-11.0
Ocean Shores	2,262	3.7	+27.3
Westport	1,935	3.2	-1.0
McCleary	1,515	2.5	+6.8
Tenino	1,295	2.1	+1.2
Pe Ell	580	1.0	-6.0
Oakville	580	1.0	+8.0
Bucoda	530	0.9	+2.1

[A] Populations of unincorporated areas not entirely in Grays Harbor Basin were estimated from data in OFM (1991).

Table 2. Chehalis Basin population (OFM 1991).

Economic Base

Forest Products

The Grays Harbor economy has always been cyclical, but has especially suffered from a combination of increased automation (GHRPC 1992) and reduced old growth timber harvest. The two largest wood products plants in the Basin are the ITT-Rayonier pulp mill in Hoquiam and the Weyerhaeuser pulp mill in South Aberdeen. The Aberdeen area also supports many smaller plants making plywood, doors, veneer, and other wood products. The export of logs and lignin liquor through the Port of Grays Harbor is important to the local economy (GHRPC 1992). Log exports are mainly to Japan, China, and Korea.

Agriculture

In 1987, agriculture in the Chehalis Basin generated an estimated $96 million per year from about 200,000 acres (WDA, unpublished 1987 data, WDA 1991). Lewis County has a greater amount of land in agriculture than other Basin counties. Farmland is about equally divided between pasture and crops. Farms average about 100 acres, and slightly over half the operators derive most of their income from non-farming sources. About 80 percent of farm income came from livestock and their products, such as beef, milk, and eggs. Of the remaining 20 percent, hay is the predominant crop while peas and corn are also important. The GHRPC (1992) lists other specialty crops such as cranberries, oysters, farm-raised trout, and Christmas trees.

Tourism

Grays Harbor County attracts more tourists than other coastal Washington counties. Tourism to Grays Harbor and Pacific Counties generated about $50 million in 1989, up $5 million from 1988 (ICF Technology Inc. 1988). Most visitors to these counties were Puget Sound residents, and less than 10 percent came from out of state (ICF Inc. 1988). Local government is promoting sport fishing as a basis for increased tourism to help compensate for some of the losses in the timber industry (Larry Wilder, Grays Harbor Tourism Council, pers. comm.). The goal is year-round sport fishing opportunity, supported by increased runs of spring and fall chinook salmon and summer steelhead (Larry Wilder, Grays Harbor Tourism Council, pers. comm.). The result of fishery improvement is expected to be reflected in increased sport fishing-related purchases at restaurants, bars, motels, and sporting goods and grocery stores.

Fishing and Related Activities

The Basin has important commercial, charter, and private sport fisheries (Table 3) and related businesses. Marinas serve commercial and recreational boats at Ocean Shores, Aberdeen, Hoquiam, and Westport. Grays Harbor also has boat construction and repair businesses, retail fishing supply houses, and associated accommodations (GHRPC 1992).

Commercial Fisheries

Most commercial fishing boats based in Grays Harbor fish outside the Harbor on chinook and coho salmon, bottomfish, and crab. The two major commercial salmon fisheries based in Grays Harbor are the troll and gillnet fisheries. The catch is processed at plants in Westport, Hoquiam, and Taholah. The amount of Washington salmon available to commercial fisheries and processors depends primarily on run sizes and harvest and escapement goals (ICF Technology, Inc. 1988), although allocation of catch to sport fisheries clearly constrains commercial opportunities in many years (Stone, WDF, pers. comm.).

Type	Fishing grounds	Target species
Sport		
Freshwater	Grays Harbor tributaries	Local steelhead, coho, chinook, chum cutthroat trout, white sturgeon
Saltwater	Ocean	Mixed stock coho and chinook
	Grays Harbor, north and south jetties, Westport and Ocean Shores marinas	Local coho and chinook and net pen stocks
Commercial		
Non-Indian		
Gillnet	Grays Harbor	Fall chinook, coho, chum, sturgeon
Troll	Marine areas outside Grays Harbor	Mixed stock coho and chinook
Indian gillnet		
Quinault Nation	Grays Harbor, Humptulips, and lower Chehalis	Spring and fall chinook, coho, chum, steelhead, sturgeon
Chehalis Tribe	Middle Chehalis River	Spring and fall chinook, coho, chum, steelhead
Indian troll		
Quinault Nation	Washington coastal and marine areas	Mixed stock chinook and coho

Table 3. Major fisheries of the Chehalis Basin and their target species (D. Stone and J. Devore, WDF, pers. comm.).

Ocean Troll Fishery. The troll fishery operates off the coast and targets mixed stocks of coho and chinook in a heavily regulated fishery. Westport is the primary troll fishing port in the Basin, and can be expected, along with Ilwaco and Neah Bay, to remain one of the major commercial ports on the Washington coast.

Terminal Area Fisheries. Grays Harbor itself supports local commercial fisheries, as well as sport fishing and oyster culture. Fish species of economic importance within the Harbor include local runs of chinook, coho, and chum salmon, steelhead, and cutthroat trout. Sturgeon, largely originating from the Columbia River, support sport and commercial fisheries in Grays Harbor and the lower Chehalis (John Devore, WDF, pers. comm.). Both the non-Indian and Indian commercial gillnet fisheries operate inside Grays Harbor. Both harvest chinook, coho, and chum salmon. In addition, the Indian fishery harvests steelhead.

Sport Fisheries

The two major recreational fisheries are the river sport fishery and the charterboat fishery. The Basin attracts anglers from outside Grays Harbor, principally from the Puget Sound metropolitan area but from neighboring states as well.

Marine Sport Fishery. The charter salmon fishery has traditionally fished only the mixed stocks of chinook and coho salmon in the ocean, but some boats have begun fishing inside Grays Harbor for local coho. There is also a sport fishery by private boats in the ocean. Westport is the primary charter fishing port in the Basin. The recreational coastal Washington salmon fishery provided about 160,000 annual trips during 1986-1988, of which slightly over half were by charter boat, and most of the rest by private boat (ICF 1988). As salmon stocks have declined many of the charter operators have increasingly turned to bottom fishing.

River Sport Fishery. The river sport fishery targets primarily on steelhead, coho, chinook, and chum salmon, and white sturgeon. The ICF (1988) analysis showed relatively little bank fishing, but may have underestimated the fishing effort along the lower Chehalis, Humptulips, Wynoochee, and Satsop Rivers.

Value of Salmon Fisheries

Pacific Northwest

The economic value of salmonid fishing in the Pacific Northwest (northern California, Washington, Oregon, and Idaho) was studied by the Oregon Rivers Council (1992). They reported that recreational users valued the experience of fishing at about $50/day in 1990 dollars. However, Pacific northwest residents were also willing to pay for the expansion of Columbia River salmon runs by paying higher utility bills at the rate of about $70 per fish, if one includes the value placed on the mere existence of the resource and the continued option of fishing, as well as the value of fishing experience itself (Oregon Rivers Council 1992).

Combined commercial and recreational salmon, trout and steelhead fisheries produced $1.3 billion in annual personal income in direct, indirect, and induced economic impacts, and supported 63,000 jobs in 1990 (Oregon Rivers

Council 1992). The commercial fishery generated $320 million in total personal income and 15,000 jobs (Oregon Rivers Council 1992). The recreational fishery added $930 million and 48,000 jobs (Oregon Rivers Council 1992). Fish-related budgets for state and federal agencies contributed at least $200 million annually and generated indirect and induced income and jobs (Oregon Rivers Council 1992).

Washington State

Salmon fishing contributed $415 million to the state and provided about 21,000 jobs in 1988; commercial salmon fisheries contributed about $136 million annually in personal income and 6,800 jobs (Oregon Rivers Council 1992). The recreational salmonid fishery produced a personal income impact of $279 million and generated about 14,250 jobs (Oregon Rivers Council 1992).

Coastal Washington

Fishing generated $48 million in income and provided about 1,000 jobs in 1988; the non-Indian commercial fisheries in 1982-1985 in Pacific and Grays Harbor Counties generated total sales and employment income of $14 million and provided 350 full-time-equivalent jobs (Table 4) (ICF Technology, Inc. 1988). By gear type, the troll fishery between Cape Flattery and the Columbia River generated income of $11.8 million from 1980 to 1989, while the non-Indian gillnet fishery in Grays Harbor and Willapa Bay produced $1.2 million (Oregon Rivers Council 1992).

	Commercial fishery	Recreational fishery
Total annual sales	$8.5 million	$22 million
Household income	$6 million	$12 million
Employment	300 FTE[A]	650 FTE
Net economic value	-$250,000[B]	$6 million

A Full-time equivalents.
B Some salmon fishermen operate profitably fishing for other species.

Table 4. 1985 Washington coastal salmon fisheries economic values (ICF 1988).

The recreational fishery generated a total household income during 1982-1985 of $34 million annually and 650 full-time-equivalent jobs (Table 4) (ICF Technology, Inc. 1988).

Westport

Commercial fishing. Commercial fishing and fish processing generated a total of $46.7 million in 1988, $33 million in sales and $13.7 million in income, and accounted for 758 jobs at the peak of the season, or 76% of all marina jobs (CH2M Hill-Northwest 1989). However, salmon was only 2.6 percent (0.9 million pounds) of the total seafood landed (28.7 million pounds), which consisted primarily of crab, shrimp, and rockfish (CH2M-Hill Northwest 1989). The personal income impact of the non-Indian troll ocean salmon fishery for Westport was $770,000 in 1991 (Pacific Fishery Management Council 1992).

Recreational Activities. Charter boat and recreational fishing and other tourism generated $6.6 million, $4.7 million in sales and $1.9 in personal income, and provided 132 jobs in 1988 (Lattin 1992). Virtually all recreational income came from outside the Westport area; 90 percent of the visitors were non-local Washington residents and 10% were from out of state (CH2M-Hill Northwest. 1989). Salmon played a larger role in the sport fishery than in the Westport commercial fishery. In 1988 roughly 50% of the charter trips were for salmon fishing; 40% for bottom fishing, and 10% for whale- or bird-watching (CH2M-Hill Northwest 1989). The economic impact of an estimated 66 private, recreation boats in the Westport Marina was not documented (CH2M-Hill Northwest 1989).

Trends in Economic Impact

Washington State

The combined ocean troll and recreational income in 1991 was 67% less than the 1976-1990 average (PFMC 1992). The estimated total state personal income generated in Washington by the non-Indian troll fleet was $2.5 million, an 84 percent decline from the 1976-1990 average, and the decrease was similar for the coastal areas, and spread evenly across Neah Bay, Westport, and Ilwaco (PFMC 1992).

Washington Coast

Non-Indian troll-caught coho landed in Grays Harbor have declined from an average of 207,500 fish for 1976-1980 to 19,300 fish for 1986-1991; Westport recreational ocean salmon fishing effort declined from 210,300 trips to 52,600 trips over the same period (PFMC 1992).

Westport

In 1980 there were 250 charter fishing vessels moored at the Westport Marina; over the next 11 years, it dropped to 65 (Stevens 1992). Estimates of personal income from the recreational ocean salmon fishery declined from the 1976-1990 average of $9.8 million (1991 dollars) to $4.1 million in 1991 (PFMC 1992).

Benefits of Stock Recovery

The potential benefits of recovery extend beyond the direct economic benefits of each additional fish because restoring a depressed wild salmon stock removes harvest constraints and thus allows more efficient harvest of all intermingled healthy runs (Oregon Rivers Council 1992). Moreover, good recreational fishing opportunity aids in attracting new industry to an area (Oregon Rivers Council 1992). Although it is difficult to accurately predict the economic benefits of salmon restoration, recovered salmon runs would obviously be positive for the region's economy.

The ICF (1988) study predicted a 10 percent increase in fishing would result in $1.3 million more in household income for the recreational fishery. Benefits would go almost entirely to boat fisheries, with the charter fleet gaining about 75 percent and the private and rental boat fishery, 25 percent. They also predicted a 10 percent increase in fishing, with no change in daily catch rate and no offsetting decline in any other fishery, would result in $634,000 more household income for the commercial fishery of the two counties. Benefits would be split between the ocean troll and the gillnet fleets.

Healthy fisheries are an important component of the Basin's economic infrastructure. Rebuilding the salmon and steelhead habitat is critical to the economic well-being of the Basin. The salmon restoration recommendations in this report will produce economic benefits by creating jobs for local workers.

Value of Sturgeon Fisheries

Commercial Fishery

The 1982-85 ex-vessel value of all Washington commercial sturgeon landings averaged $350,000 annually (ICF 1988). About 15 percent of the statewide commercial sturgeon harvest originated in Grays Harbor, primarily from the gillnet fishery (ICF 1988).

Recreational Fishery

Less than 10 percent of the Washington sport harvest comes from Grays Harbor; the majority comes from the lower Columbia River (ICF 1988). Sport sturgeon fishing generated about $323,000 annually in Pacific and Grays Harbor Counties during the study period (ICF 1988). About 96 percent of the expenditures involved in-state dollar transfers rather than new money for the state. The recreational sturgeon fishery had a much different makeup than the salmon fishery. About two-thirds of the income was generated by bank fishing trips, and about one-third by private or rental boats (ICF 1988).

Social Values Connected with Fishing

Tribal Fishing

The Tribes' fishing rights are indispensable to maintaining a cohesive tribal society. Two tribes fish the Grays Harbor Basin; the Quinault Indian Nation and the Chehalis Indian Tribe. Their goal is to perpetuate their salmon-dependent culture and promote the economic welfare of their members.

River Sport Fishing

The Chehalis and its primary tributaries downstream of Porter support a significant sport fishery. The Washington Department of Fisheries recently emphasized sport fisheries while maintaining, but not increasing, commercial fisheries (WDF 1991). However, under the present management scheme there is little fishing opportunity upriver from Porter, where there were once larger runs of all species. River sport fishing is an important cultural interest of Basin residents so there is high interest in restoring fishing opportunity. Public participation in fishery enhancement projects seems motivated as much by civic pride and commitment to the local community as by expectation of economic development.

Marine Fishing

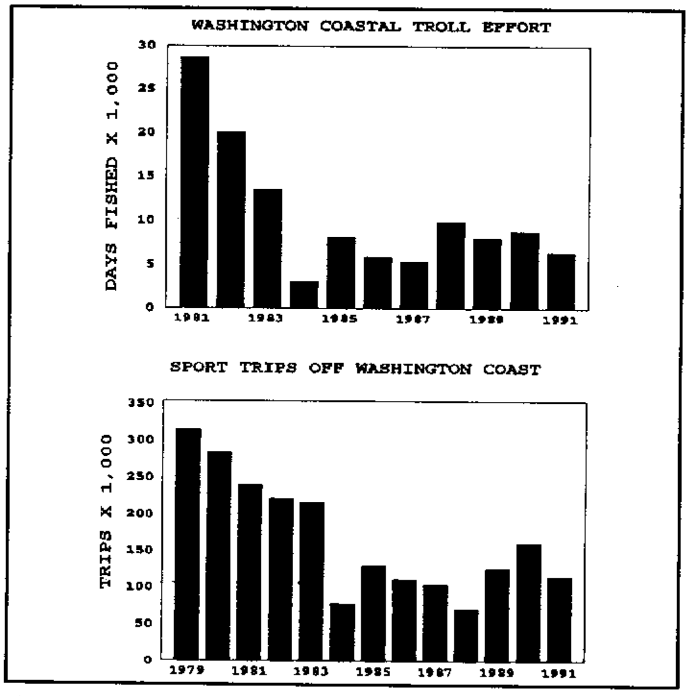

Figure 4. Washington ocean salmon fishing effort (PFMC 1992).

Many of the Basin's families are connected to fishing. The community of Westport, in particular, is based on ocean fishing with success tied directly to the size of health of fish runs. Charterboat and ocean troll fishing has decreased statewide (Figure 4) along with reduced seasons. However, groups representing both these interests have promoted rebuilding Grays Harbor stocks, even though they often harvest mostly Columbia River fish. In 1991, charterboats began fishing inside Grays Harbor to exploit the very abundant Chehalis coho run of that year (Mark Cedergreen, Westport Charter Association, pers. comm.).

Chapter 2: HISTORICAL ACCOUNT OF THE FISHERY RESOURCES AND HABITATS

The history of Chehalis Basin fish runs and habitats is one of pristine productivity, then gross degradation, followed by partial recovery. The recorded history has seen several revolutions in fishing methods and areas, and in industries and processes affecting fish habitat. In the first several decades of this century, unregulated log transport and fishing, overlapping in time with inadequate water pollution control in the inner Harbor, contributed to declining salmon and steelhead catches in the Grays Harbor area.

In response, the State imposed fishing regulations and later saw to the removal of splash dams (see discussion on logging later in this chapter) and restocked the streams behind them. Research into habitat quality began in 1940 and prompted a series of water cleanup efforts that continue (Pine and Tracey 1971; Seiler 1989). Unfortunately, this did not promote a speedy recovery of fish stocks and a long period of depressed terminal catches followed.

All the while, increasing marine interception may have masked potential recovery of coho and chinook (John Campbell, Weyerhaeuser Corp., pers. comm.). During the 1950s, chum salmon joined chinook, coho, and steelhead on the list of depressed runs (Ward *et al.* 1971), and steelhead catch monitoring had been discontinued (WDW unpublished records), adding to the frustration.

Accurate catch and escapement monitoring began around 1969. The 1970s brought about an era of increasing understanding of the fishery and habitat resource, and increasing participation by all groups having a stake in those resources.

Since catch is a result of fishing efficiency, environmental conditions, and fish production, this report will provide a history of fishing on Chehalis Basin runs, a brief description of the Basin's environmental history, and a history of hatcheries.

HISTORY OF FISHING ON CHEHALIS BASIN SALMON AND STEELHEAD

The history of fishing for salmon, and to a lesser degree, steelhead, has seen a growing diversity of fishing gear and expansion of fishing areas. Fishing on Chehalis Basin runs progressed seaward as each new fishery became the first to intercept fish along the migratory path of returning adults. Ultimately, Chehalis Basin fishery managers lost their ability to ensure a surplus of fish for harvest and spawning within the Chehalis River Basin.

Chehalis River Basin Fisheries

Fisheries have tended toward multiple gear types and expansion of fishing grounds. Before European contact, various Indian tribes or bands fished Grays Harbor for salmon, steelhead, cutthroat trout, and sturgeon with weirs and other terminal gear (GHRPC 1992). Settlers began arriving in the 1850s and, by 1877, were using fish traps (GHRPC 1992) downstream of Indian weirs to supply a salmon cannery. Thus began the conflict between upriver and downriver fisheries that continues even to some degree today.

Later, fish traps were built along the shores of Grays Harbor; next, Grays Harbor gillnetters jumped ahead of the trap fishery by exploiting open waters of the Harbor (Wendler and Deschamps 1955b). By 1892, when the commercial catch was first reported (WDF, unpub. records), set and drift gillnetting were legally recognized along with trapping. By 1934, harvests had declined and the trap and setnet fisheries were outlawed, apparently to stabilize harvest (Wendler and Deschamps 1955b).

In the 1950s, nylon gillnets were introduced and quickly replaced cotton and linen nets, making the Grays Harbor drift gillnet fishery more efficient.

In 1974, the Federal Court ruled that western Washington tribes having signed treaties with the United States in the 1850s reserved half the harvestable fish passing through their usual and accustomed -- that is, historic -- fishing grounds (for example, see Northwest Indian Fisheries Commission 1989). This resulted in a reallocation of catch by a reduction in mixed-stock, open-ocean fisheries and increased terminal area returns and stream-by-stream fishery management throughout western Washington (Dr. Percy Washington, Gaia Inc., pers. comm.). Locally, it also led to expansion of Quinault tribal fisheries off the Quinault reservation and onto Grays Harbor and the Humptulips and Chehalis rivers (Hiss *et al.* 1982).

Marine Interception

Virtually all fishing on Chehalis Basin salmon originally occurred inside the Basin, but, around 1935, fishing boats were fitted with economical diesel motors. Trollers began to exploit the mixed stocks in the ocean (Wendler and Deschamps 1955b). Boats could now easily run to ocean fishing grounds and intercept fish before the runs reached Grays Harbor, Willapa Bay, and the Columbia River. The ocean troll fishery increased tenfold from 1940 to 1970 (Grays Harbor Regional Planning Commission 1992). This resulted in loss of harvest control by local managers (Washington 1988 draft). In the late 1940s, charterboats joined trollers in the marine fishery. By 1950, WDF began keeping catch records from this fleet. The fleet continued to grow steadily and peaked in 1977 (Ward and Hoines 1985).

As ocean fleets developed at all Pacific coast ports, Chehalis Basin chinook and coho were caught off the coasts of Alaska, Canada, and Oregon as well as Washington (now known from coded-wire tagging data). Prior to 1976, individual states managed marine fisheries. But, in that year, the Magnuson Fishery Conservation and Management Act created the Pacific Fishery Management Council, with the duty of setting fishing seasons and limits for marine waters between 3 and 200 miles off the coasts of California, Oregon, and Washington.

However, the Act did not address the issue of Canadian interceptions. The Pacific Salmon Commission (PSC) was formed in 1985, as a result of the Pacific Salmon Treaty between the United States and Canada, to prevent overfishing, increase salmon production, and ensure each country receives benefits equal to its own production (PSC 1988).

Although recent increases in Washington coastal chinook escapements might be attributable to reductions in interception under the Treaty, to date the Treaty has not entirely satisfied the desire for increased terminal fishing opportunity in Grays Harbor. Further significant changes in U.S. and Canadian fishing patterns will depend on continuing international negotiation.

While the overall catches of chinook and coho have declined over the past 20 years, catch reductions were not equally shared coastwide (Figure 5). Marine chinook catch landed in Washington decreased more than that of Canada over the last 20 years, while the southeast Alaskan catch remained about the same. Washington coho landings decreased more than those of Oregon, while the Canadian catch remained about the same.

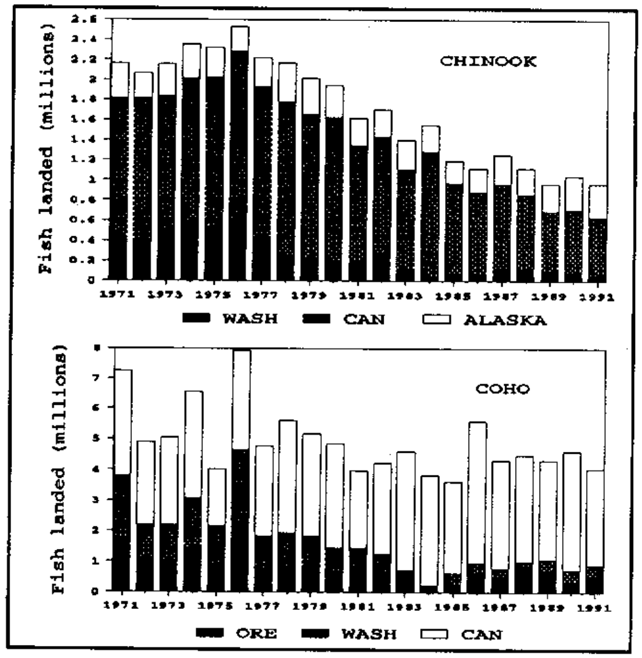

Figure 5. Landings from ocean troll and recreational fisheries (PFMC 1992).

HABITAT HISTORY

Fish habitat in the Basin has been subjected to progressive degradation from agriculture, pulp production, gravel mining, dams, urbanization, and dredge and fill practices. Over the last 50 years, there has been a movement, now accelerating, that has partially succeeded in slowing habitat deterioration. As the primary economic focus in the Basin changed through time, the habitat battleground has constantly shifted.

Historically, agriculture was the first land use to conflict with natural fish production. Later, the heyday of logging and pulp production resulted in gross abuses to salmon habitat. As the Basin developed, gravel was mined from the rivers for road building, at the expense of salmon spawning grounds. While all these economic developments have ultimately had to concede a place for the fish, they have given us a legacy of partially resolved technical and political questions. Chapter 5 describes how each economic development has impacted fishery habitat; the history of these developments is addressed here.

Agriculture

Agriculture exacted a price from the fishery resource beginning when the Basin was first opened to cultivation. The story of agriculture and ranching is one of early fish habitat damage, historically largely undocumented and unredressed, followed by a recent movement toward compatibility with aquatic habitat. In 1857, the City of Hoquiam was founded, with agriculture as its economic base. The demand for dairy products for the Fraser River gold rush stimulated Hoquiam's development. Bringing land under cultivation had four effects:

Removing Side Channels, Sloughs, and Ponds.- Farmers diked certain riverfront land on the Chehalis and its principal tributaries, especially the Wynoochee, Satsop, and Humptulips, and to a lesser degree the Skookumchuck and Newaukum (GHRPC 1992). This destroyed winter cover and feeding areas for juvenile coho salmon and cutthroat trout. River confinement is also thought to have stimulated scouring, thus artificially lowering river elevations.

Straightening Small Streams.- Straightening of small tributary streams to allow more convenient grazing and farming resulted in loss of total stream area and the essential habitat variation of the riffle/pool complex. Examples are Hanaford Creek and Bloom's Ditch (Phinney *et al.* 1975).

Clearing the Bank of Trees.- This removed the shade tree canopy along some tributaries, contributing immediately to warmer water, and, over the long term, to less input of woody debris for fish cover.

Snagging, or Logjam Removal.- In the 1880s, the USACE cleared many streams of logjams, which were apparently thought to promote erosion, flooding and channel shifting wherever jams were located.

Logging

This section will describe some of the damaging timber harvest practices now prohibited by existing WDNR regulations. The effects of past timber harvest practices, although sometimes obvious, are usually maddeningly difficult to measure and link to specific degrees of fishery damage.

History of the Industry

In the early 1880s, timber harvest joined agriculture as a major economic activity (Grays Harbor Regional Planning Commission 1992). In 1882, Grays Harbor's first sawmill was built on the Hoquiam. In 1909, the demand for logs grew quickly for use in rebuilding San Francisco after the fire and earthquake. Thus arose the need to quickly transport many logs from the woods to the Harbor. Before the advent of modern logging equipment and practices, the most efficient way to transport logs to the mills was by water; giving rise to the era of splash dam logging. Logging and driving companies constructed a system of log dams to maintain ponds for holding logs and to create a supply of water to move their cut timber (Wendler and Deschamps 1955b). Log splashing usually occurred weekly. The gates of each dam were suddenly opened and the logs behind the dam sluiced through the gate and carried downstream by the flow.

This was apparently the most ecologically damaging period the Basin has known (Wendler and Deschamps 1955a). Almost all the structures were total blocks to anadromous fish and eliminated considerable spawning and rearing areas (Figure 6). These barriers effectively blocked over 60 percent of the salmon spawning and rearing streams of Grays Harbor. The average splash dam was in place about 20 years.

The downstream impacts included:

(1) mechanical injury to eggs and fish spawning below the dam,
(2) destabilization of gravel beds by moving logs or suddenly increased flows, with the resultant disappearance of distinct riffles and pools,
(3) channel instability,
(4) deposition of bark over a large part of the stream bottom between splashes,
(5) unnatural shading of many miles of tidewater by log rafts, and
(6) loss of fish cover by clearing woody debris from stream channels.

In the 1930, the timber industry began undergoing a technical revolution as roads and railroads began to replace rivers for log transport (Wendler and Deschamps 1955b), and the dams became obsolete. Many operators abandoned the installations without attempting to remove them. Some fish ladders were constructed where feasible, but many did not work efficiently. Many dams blocked migrating fish until they either rotted out, washed out, or were removed by WDF in the early 1950s. After removal, rapid natural recolonization was observed in several instances. In addition, hatchery-reared fish, usually coho fry, were at times planted upstream to speed recovery.

A significant change occurred in the logging industry in 1962 when very high winds blew down extensive timber, creating the need to remove a large number of logs before decay set in. The permanent effect was that Japan became a major buyer, and Weyerhaeuser Company a major exporter, of Chehalis Basin logs (Felver 1982, quoted by Grays Harbor Regional Planning Commission 1992).

Continuing Effects of Old Logging Practices

Shade Removal. Economically valuable trees were usually removed down to the streambank until the last decade. Until shade trees grow back, an exposed stream tends to become warmer and, if it gets too warm, salmon and steelhead cannot use it. If this happens to a number of streams, temperatures may increase downstream as well.

Sources of Instream Fish Cover Removed. Lack of woody debris naturally entering the stream over the years resulted in lost habitat complexity until some point in the last decade. This situation especially hurts juvenile coho and adult chinook and, to a lesser extent, juvenile steelhead, because it denies them instream cover. Further misguided efforts to remove logging

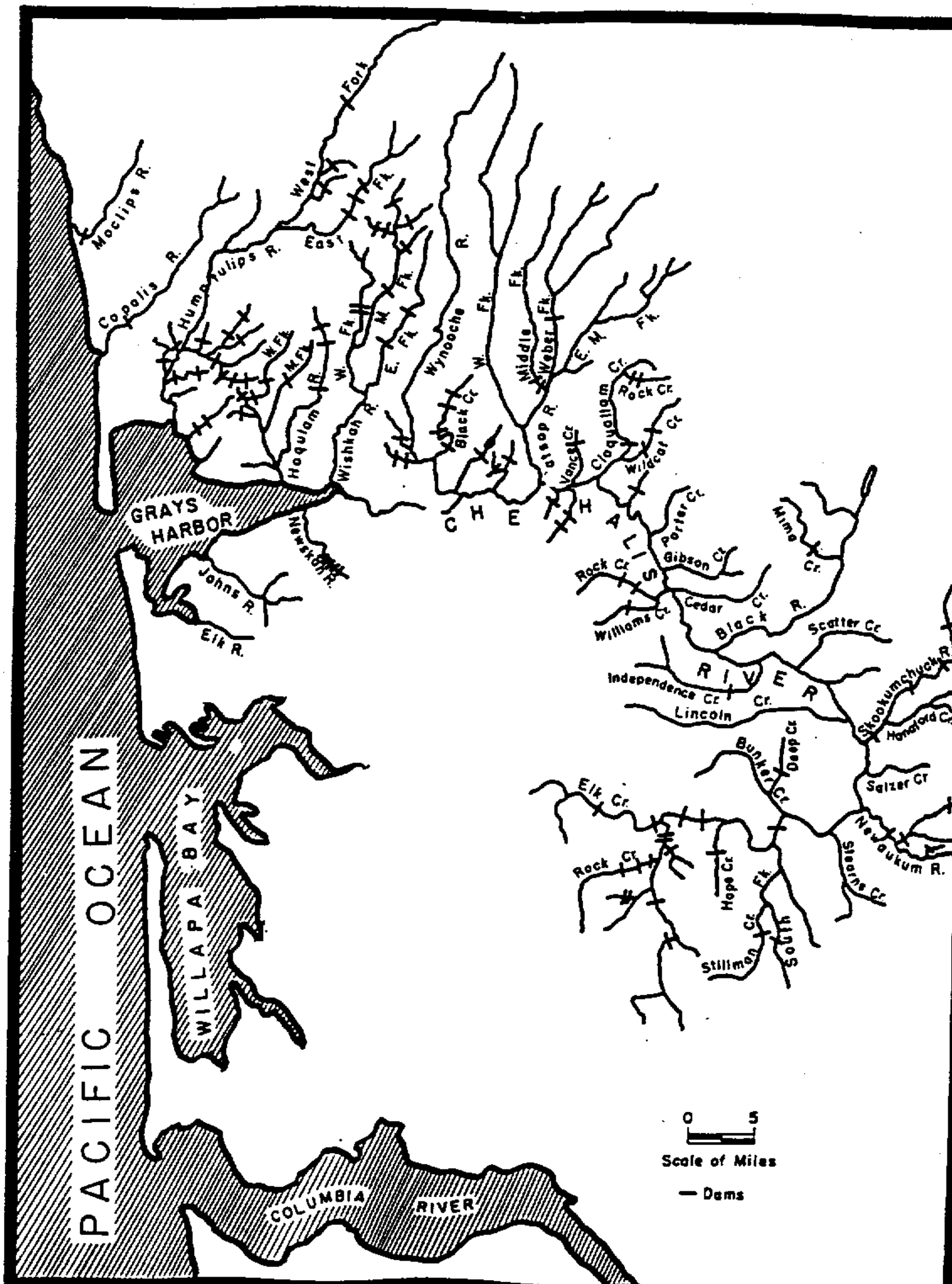

Figure 6. Past location of splash dams (Wendler and Deschamps 1955b).

debris from streams in the previous decades may have actually diminished productivity in many areas. The upper Chehalis, from Fisk Falls at Mile 113 upstream to several miles beyond the Forks of the Chehalis, exemplifies this problem.

Stream Channel Destabilized. Logging can also reduce fish production by reducing the stability of the watershed and the streambed. To the degree that logging roads and other activities accelerated the natural process of slope failure, they led to an unnaturally high rate of bedload and silt accumulation (Cederholm and Reid 1987). This can lead to an unstable streambed, in which high flows tend to rapidly shift the channel, scour spawning gravels, and wash fry that cannot hold their position against the flow downstream. Porter Creek is a likely case of gravel and sand loss attributable to logging.

Recent Forest Practices Improvements

The current trend seems to be slow but steady progress toward compatibility between forestry and fishery resources. The last decade has seen intense interagency effort to make timber harvest compatible with fishery values. In 1980, in Phase II of *U.S. vs. Washington*, Judge William Orrick ruled that fish habitat protection was a treaty right (Cohen 1986). This led to tribal participation in fish habitat protection on the technical and management levels. The specter of continual controversy over the relation between fisheries and forest practices led to the development of the Timber, Fish, and Wildlife Agreement (TFW), wherein all principal parties influenced by forest practices have an opportunity to participate in reducing the detriments.

The 1990 decision to list the Northern Spotted Owl as a federally threatened species resulted in a reduction of old growth timber harvest which should reduce some stream degradation to the benefit of salmon and steelhead.

Gravel Mining

As the Basin population grew and roads replaced rivers for log transport, gravel for roads and general construction came into high demand. Gravel extraction from the wetted channel became popular shortly after the end of the splash dam era, since river-run gravel is especially useful for road-building. At first, draglines and clamshell buckets were commonly used to remove gravel from pits in the main river channel.

By 1945, WDF required permits for such work, and applications increased annually (WDF 1986). In the 1950s, WDF recognized the damage and prohibited gravel mining in the wetted channel. However, gravel mining was allowed to continue on the dry bars during low water. The Humptulips was the main gravel producer, followed by the Satsop and Wynoochee.

Since then, progressively stricter state and county regulation has eliminated the most damaging effects, and has also successfully encouraged operators to seek gravel from off-channel sources. In 1960, WDF permits further restricted gravel mining by requiring gravel removal by bar scalping, as opposed to pit construction (WDF 1986). Bars had to be smoothly sloped after scalping to avoid trapping fish as the river rose and fell. In 1975, WDF further restricted gravel removal by closing the Humptulips to new bar scalping above RM 15 (WDF 1986). The wisdom of this move was confirmed by Collins and Dunne (1986, quoted in Mark *et al.* 1986) who showed that gravel mining on the Humptulips had been taking up to 10 times more than the river could replenish in an average year.

Gravel scalping is still permitted up to the transport rates derived by Collins and Dunne (1988) for the Humptulips, Wynoochee, and Satsop. Annual removal is divided equally among gravel removal applicants for river of interest. Special state legislation after the 1990 flood allowed a single gravel removal operator to remove seven times the transport rate on the Humptulips to help reduce the risk of flood damage. A special provision of the legislation closed the Humptulips to further gravel removal for 7 years. Presently, there are 6 years remaining on this provision. The Satsop and Wynoochee rivers receive only an average of one to two applications per year. The added restrictions on gravel bar scalping (removal) combined with decreased demands has made this type of gravel removal nearly economically unfeasible.

Urbanization

As the Basin was settled, urbanization permanently altered the aquatic resource. Streets, buildings, bridges, culverts, and levees appeared, and towns required water supplies and sewage disposal. Streets and buildings created urban stormwater runoff, exacerbating both flooding and streambed instability. Culverts under roads and city streets were seldom designed to allow fish to pass upstream.

Those towns not built on filled land often encroached onto floodplains -- a process still in full force today in the upper Chehalis. Levees were built in Centralia, Aberdeen, and Cosmopolis to protect development in the path of the river, but levees typically cut off seasonally valuable fish habitat.

Water rights were granted to cities, industries, and individual homeowners on the philosophy that the best use of water was always for economic development, i.e., use outside the natural stream. Only in the 1970s was action begun to protect instream resources (Mahlum 1976).

Originally, all urban sewage was discharged untreated into the nearest water body; sewage plants were not in operation, for instance, in the Aberdeen area until 1957 (GHRPC 1992). This made parts of the middle and lower Chehalis River uninhabitable for fish for at least the summer and early fall (WDOE et al. 1974).

Estuarine Dredging and Filling

Since the turn of the century, log exports have driven the Grays Harbor shipping industry, requiring a navigation channel from the ocean to the inner

Harbor log docks. In 1911, the Port of Grays Harbor was organized for the purpose of dredging, filling, and wharf construction. The increasing size of log-export vessels forced successive deepening of the navigation channel from Westport to Cosmopolis in 1923, the late 1940s, 1973, and 1990. The most important historical effect of dredging has been filling of wetlands, particularly in the vicinity of the Cow Point (Figure 2) (GHRPC 1992).

Landfills in the Grays Harbor tidelands created much of downtown Aberdeen and Hoquiam, and removed extensive rearing habitat for chum, chinook, and coho salmon. Dredged material, along with sawdust and bark from sawmills, was used to fill the tidelands. Wetland filling is now regulated by the USACE and has been substantially reduced. However, the full range of other environmental effects of dredging and of dredged material disposal has only been addressed in the two most recent navigation channel widening and deepening episodes, particularly the current one. The most recent harbor deepening, soon to be completed, is the first to have extensive environmental evaluation built into the project (Ging 1988).

Dams and Diversions

Besides the splash dams described above, other relatively small dams and diversions have been constructed in the Basin over the years (USDA et al. 1974; GHRPC 1992) for municipal and industrial use. A few of these dams have blocked access to upstream spawning and rearing habitat (Phinney *et al*. 1975). The incremental effect of numerous withdrawals in some streams has seriously reduced flow, reducing spawning and rearing habitat and exacerbating poor water quality (Fraser 1986).

The Skookumchuck and Wynoochee Reservoirs are by far the two largest dams in the Chehalis Basin. The Skookumchuck was finished in 1970, and the agreed-upon fishery mitigation was fully in place shortly thereafter (Hiss et al. 1982). The Wynoochee Dam was completed in 1974. Unlike the Skookumchuck, the Wynoochee mitigation is yet to be completely agreed upon (for example, see Riley 1992).

Industrial Waste Disposal

Water quality in Grays Harbor is intimately linked to pulp production. Since its inception in the late 1920s, pulp production appears to have depressed fish survival and created conditions popularly known as the "pollution block" (WDF 1971). At least until very recently, the pollution block limited the effectiveness of potential improvements in habitat and hatchery production throughout the Chehalis system. However, successive changes to mill waste treatment and pulp-making processes have led to stepwise estuarine water quality improvements near the mills. Research in the 1940s identified lack of dissolved oxygen in the inner Harbor as the prime suspect (Eriksen and Townsend 1940). When pollution was controlled enough to restore sufficient oxygen for fish in the inner Harbor, fish survival still appeared poor, and investigators attempted to identify toxic substances that waste treatment failed to remove. The most recent evaluation of fish survival (Schroder and Fresh 1992) suggests toxicity from unidentified substances as recently as

1989. However, effluent clean-up since that date may have finally removed the "block". Data on fish survival through the presumably cleaner inner Harbor will be available over the next several years. A detailed account of inner Harbor water quality appears in Chapter 4.