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Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America

WATER TRANSPORTATION AND STORAGE OF LOGS

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ABSTRACT

Environmental effects of water transportation of logs in western North America include the historical driving of logs in rivers and streams, and the current dumping, sorting, transportation, and storage of logs in rivers and estuaries in British Columbia and southeastern Alaska.

The historical discussion focuses on habitat losses and volumes of logs transported by water, both freshwater and marine. Many changes in stream-channel structure and habitat simplification still exist today, nearly 100 years after river-driving activities have ceased.

The environmental effects of current log handling on the physical habitat, water quality, plant communities, benthic and intertidal invertebrates, and fish are reviewed. Information gaps are identified and needed research is recommended.

The environmental effects of log handling are generally localized. Regional differences in intensity of aquatic and marine log transportation are discussed for Oregon, Washington, British Columbia, southeastern Alaska, Idaho, Montana, and California, to provide perspective on the volume of logs transported and areal extent of the estuarine and river habitat allocated to log transfer and storage. The most intense aquatic log handling occurs in British Columbia, Oregon, and Washington.

Guidelines and recommended practices developed in the 1970's by a west coast task force are described. These recommended guidelines minimize adverse environmental impacts.

KEYWORDS: Log transportation, log storage, anadromous fish habitat, plant communities, intertidal invertebrates. Pacific Northwest, southeast Alaska.

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INFLUENCE OF FOREST AND RANGELAND MANAGEMENT ON ANADROMOUS FISH HABITAT IN WESTERN NORTH AMERICA

William R. Meehan, Technical Editor

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PREFACE

This is one of a series of publications on the influence of forest and rangeland management on anadromous fish habitat in western North America. This paper addresses the environmental effects of water transportation and storage of logs in rivers and estuaries on fish habitat. Our intent is Co provide managers and users of forests and rangelands with the most complete information available for estimating the consequences of various management alternatives.

In this series of papers, we will summarize published and unpublished reports and data as well as the observations of scientists and resource managers developed over years of experience in the West. These compilations will be valuable to resource managers in planning uses of forest and rangeland resources, and to scientists in planning future research.

Previous publications in this series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.
2. "Impacts of natural events," by Douglas N. Swanston.
3. "Timber harvest," by T. W. Chamberlain.
4. "Planning forest roads to protect salmonid habitat," by Carlton S. Yee and Terry D. Roelofs.
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9. "Forest chemicals," by L. A. Norris, H. W. Lorz, and S. V. Gregory.
10.. "Influences of recreation," by Roger N. Clark, Dave R. Gibbons, and Gilbert B. Pauley.
11. "Processing mills and camps," by Donald C. Schmiege.
12. "Rehabilitating and enhancing stream habitat: 1. Review and evaluation," by James D. Hall and Calvin 0. Baker.
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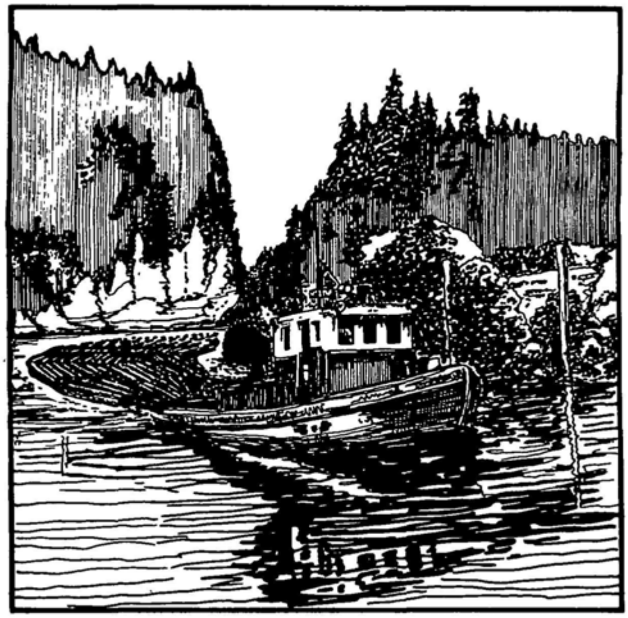
COMMON AND SCIENTIFIC NAMES OF FISHES MENTIONED IN TEXT AND TABLES 1/

Common name	Scientific name
Herrings	FAMILY Clupeidae
Trouts	FAMILY Salmonidae
Pink salmon	*Oncorhynchus gorbuscha* (Walbaum)
Chum salmon	*Oncorhynchus keta* (Walbaum)
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Sockeye salmon	*Oncorhynchus nerka* (Walbaum)
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)
Cutthroat trout	*Saimo clarki* Richardson
Rainbow (steelhead) trout	*Saimo gairdneri* Richardson
Dolly Varden	*Salvelinus malma* (Walbaum)
Smelts	FAMILY Osmeridae
Surf smelt	*Hypomesus pretiosus* (Girard)
Capelin	*Mallotus villosus* (Muller)
Longfin smelt	*Spirinchus thaleichthys* (Ayers)
Eulachon	*Thaleichthys pacificus* (Richardson)
Codfishes	FAMILY Gadidae
Surfperches	FAMILY Embiotocidae
Shiner perch	*Cymatogaster aggregata* Gibbons
Ronquils	FAMILY Bathymasteridae
Searcher	*Bathymaster signatus* Cope
Clinids	FAMILY Clinidae
Combtooth blennies	FAMILY Blenniidae
Sand lances	FAMILY Ammodytidae
Pacific sand lance	*Ammodytes hexapterus* Pallas
Scorpionfishes	FAMILY Scorpaenidae
Rockfish	*Sebastes* spp.
Sculpins	FAMILY Cottidae
Righteye flounders	FAMILY Pleuronectidae
Yellowfin sole	Limanda *aspera* (Pallas)

1/From "A List of Common and Scientific Names of Fishes from the United States and Canada," American Fisheries Society Special Publication 12, Fourth Edition, 1980, 174 p.



INTRODUCTION

Transportation is one of the major problems facing the entrepreneur in the lumber industry. In 1913, Bryant (p. 121) hypothesized that the "transportation of forest products to mill or market represents 75 percent or more of the total delivered cost of raw material, exclusive of stumpage value." Log transportation and stumpage acquisition and value are still the two major costs before the mill processes. Logs have always been considered a heavy, bulky, and cheap commodity that could not stand expensive transportation charges. Those successful in the lumber industry had to become specialists in transporting logs over the long distances that separated the primary producer and the consuming market. Indeed, the transportation of logs is still one of the central pivots around which success or failure of a lumbering operation revolves.

In the past, transporting the logs inexpensively was the industry's biggest concern. Only in the last decade has concern for aquatic or coastal marine environments been a main consideration. In earlier days, river navigation and sawmill waste resulted in environmental changes that are still detectable. Present environmental concerns over log handling in coastal waters are well documented for intertidal areas but less so for subtidal environments.

Environmental impacts of water transportation of logs in western North America can be divided into the historical driving of logs in rivers and streams, and the current dumping, rafting, and storage of logs in rivers and estuaries in British Columbia and southeastern Alaska.

The historical perspective focuses on habitat losses and volume of logs transported by water, both freshwater and marine. Many changes in stream-channel structure and habitat simplification still exist today, nearly 100 years after river-driving activities have ceased.

The current environmental concerns in British Columbia and southeastern Alaska, as well as in a few locations in Oregon and Washington, draw extensively on excellent summaries, reviews, and task-force reports from both Canada (Duval and others 1980) and the United States of America (Hansen and others 1971).

The objectives of this paper are to: review and describe historical log transportation in rivers, which was extensive in the western United States and eastern British Columbia; provide a perspective on the volume of logs transported and areal extent of the estuarine and river habitat allocated to log transfer and storage; and describe the environmental impacts of log transfer and storage that relate to fish habitat.

HISTORICAL LOG TRANSPORTATION

Numerous books have described the history of the timber industry, and many articles have glorified log drives on rivers. Only one significant book (Rector 1953) has been published on the extent and role that water transportation played in the early days of the timber industry. A book-length manuscript-A-'was produced from research undertaken for the State Lands Division of Oregon, in which the extent of navigation was determined for each of Oregon's river basins. Each of the 23 basin studies was issued as a navigability report from the State Lands Division in Salem. These two documents record the extent, duration, and dependence on water for log transportation,

The first sawmills on the west coast, between 1840 and 1870, were supplied with logs from trees that had grown at the edge of bays or large rivers. The trees were felled directly or rolled into the water, and the logs were then floated to the mills (Cox 1974).

By the early 1880's, the best timber within 2 miles of the entire shoreline of Hood Canal had been cut (Buchanan 1936). The same was true of most other readily accessible areas. Loggers constantly sought out streams along which the timber had not yet been cut. If a stream was large enough to float logs, it was soon in use. A newspaper (The West Shore 1883, p. 128) announced in 1883 that in Columbia County, Oregon, every "stream of any size has been cleared of obstructions, so that logs can be run down them in the high water season." By the end of the 1880's the same was true of almost any county along the lower Columbia, around Puget Sound, or along the "lumber coast" (Cox 1974). The centers of the timber industry reflected this dependence on water (fig. 1).

Historically, the lumber industry in the Pacific Northwest had its markets in San Francisco, San Diego, and the Pacific Rim countries. The industry depended on markets reached by sea. Thus, mills were located at seaports or along the lower Columbia River (Cox 1974). Many of these early lumber centers had disappeared by the turn of the century. The big lumber centers today are still usually located where they can service both rail and sea cargo markets.

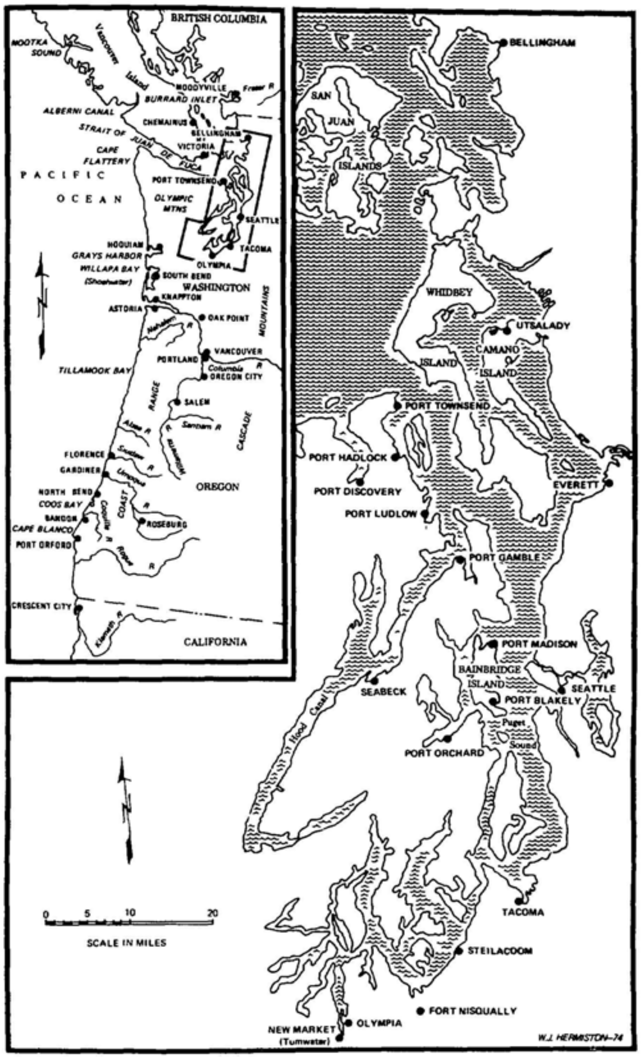


Figure 1.—Lumber centers of the Pacific Northwest before 1900 (from Cox 1974).

COMMERCE CLAUSE AND NAVIGABLE STREAMS

From the earliest days, efforts to improve streams have encountered legal difficulties. To keep mill owners and farmers from blocking the rivers with dams and other obstructions, a stream had to be declared navigable. In

Personal communication, James E. Farnell, Division of State Lands, Salem, Oreg.

Michigan, Wisconsin, and Minnesota, the courts decided Chat a stream that could float a saw log was a "public highway" and chat saw logs had just as much right to be on the rivers as rafts, barges, and steamboats. Navigable streams were not to be blocked by bridges, piers, fences, or duck ponds. At the same time, lumbermen were not to build storage and splash dams without special legislative permission (Rector 1953).

The United States Government transferred ownership of the beds of the navigable waterways to a State when it entered the Union. To ascertain which riverbeds were transferable, the U.S. Supreme Court defined a navigable river as:

> Those rivers must be regarded as public navigable rivers in law which are navigable in fact. And they are navigable in fact when they are used, or susceptible of being used, in their ordinary condition, as highways for commerce, over which trade and travel are or may be conducted in the customary modes of trade and travel on water. (The Daniel Ball 1870)

Washington, Oregon, and California all must in general comply with this definition of navigable waters.

In Washington, any stream capable of successfully floating logs was considered a floatable stream, and the logger had a right to use its waters to float logs toward the mill or market. Even though a stream was completely incapable of such log floating during the dry season, its waters were public if natural freshets provided enough water to float logs. If the stream was reasonably capable of navigation by boats or canoes and commerce was carried on, then the State owned the streambed. If the stream was floatable, but not navigable in the usual commercial sense, then the adjoining landowner or owners owned the bed of the stream. In both instances, the waters were public and the public could use them. The State had exclusive control of these so-called floatable waters. The United States Government had overriding control of truly navigable waters although the States had jurisdiction. Streams too small to float timber were considered private, and loggers probably would not use such streams unless they owned them. Thus, the logger had no right over the objections of the riparian owner to put in roll dams to cause backwaters or splash dams to create artificial freshets. The boom and driving companies were able to obtain the right to drive a floatable stream because they were quasi-public corporations (Bridges 1910). As such, they had the power of eminent domain and could run their splash dams by condemning the property and paying in advance to every landholder adjoining the stream.

Even though litigation frequently resulted, most streams in western Oregon and Washington were used for log drives.

LOG DRIVES AND RIVER IMPROVEMENTS

Log driving is the process of transporting logs by floating them in loose aggregations in water with the motive power supplied by the natural or flushed streamflow. At first, all timber within easy access of the stream was cut and floated down the adjacent river. If timber was too far away to be profitably hauled by oxen Co the mill or stream, the logger moved to another location. Gradually, loggers had to go greater distances for timber, which introduced the use of river landings, log yards, log driving, rafting, towing, and booming (Rector 1949). Still later, the more distant timber required the use of splash dams and sluiceways, expensive stream improvements, canals, tramways, trestles, log chutes and slides, trucks, and railroads for floating and driving.

As more logs were needed, artificial freshets were created by splash dams. A splash dam was a device for turning tiny streams into torrents large enough to float logs. A dam would be built on a stream and water stored behind it. When a large head of water had been accumulated, it would be released and would quickly sluice logs that had been dumped into the pond behind the dam—together with others collected along the watercourse below the dam—to where they could be handled by conventional means.

Streams of all sizes had to be "improved" before a log drive could begin. Principal forms of stream improvement were (Brown 1936):

- Blocking off sloughs, swamps, low meadows, and banks along wider parts of the streams by log cribbing to keep the logs and water in the main stream channel.
- Blasting out or removing boulders, large rocks, leaning trees, sunken logs, or obstructions of any kind in the main bed during periods of low flows. Obstructions or accumulations of debris—such as floating trees, brush, and rocks--often caused serious and expensive log jams during the driving seasons. Frequently, small, low-gradient streams were substantially widened during log driving, as a result of the frequent flushing of the stream by splash dams and by the impact of the logs along the streambank.

The historical methods of stream cleanup and improvement in the Pacific Northwest were determined from interviews with pioneers, county court records. State court records, and U.S. Army Corps of Engineers reports. An example is from the Samish River, Washington, in 1880, as told by E. E. Watkinson:

> Since no logs had ever been driven down the Samish River before, E. E. and Milbourne Watkinson began the backbreaking task of cleaning out the river which was then a network of sloughs, islands and jams with no main channel. For the purpose several Indians were hired. Islands were cleared of brush which was towed ashore on a slab raft and burned. During this campaign the river was cleared from about 2 miles above Alien to saltwater. (Jordon 1962)

The length of river was just a few miles and took 4 months to clear.

Court records also give good accounts of activities to clear obstructions on different rivers and streams. East Hoquiam Boom and Logging Company vs. Charles Nelson and others (1898) describes the continued improvement of the stream ". . .by removing fallen trees, snags, roots, jams of logs and other obstructions ..." from the "... narrow, crooked streams varying in width from forty to a hundred and fifty feet and containing numerous shallows and sandbars" (p. 143). "It also appears that the annual expense of keeping the streams clear of obstructions, so as to enable the logs to be floated, thereon, between plaintiff's upper dam and tide water, amounts to hundreds of dollars" (p. 145).

By 1900, over 130 incorporated river- and stream-improvement companies were operating in Washington. The distribution of major splash dams in western Washington and western Oregon is illustrated in figures 2 and 3. Over 150 major dams existed in coastal Washington rivers, and over 160 splash dams were used on coastal and Columbia River tributaries in Oregon. The splash dams shown represent only the main dams that operated for several seasons. On many smaller tributaries, temporary dams

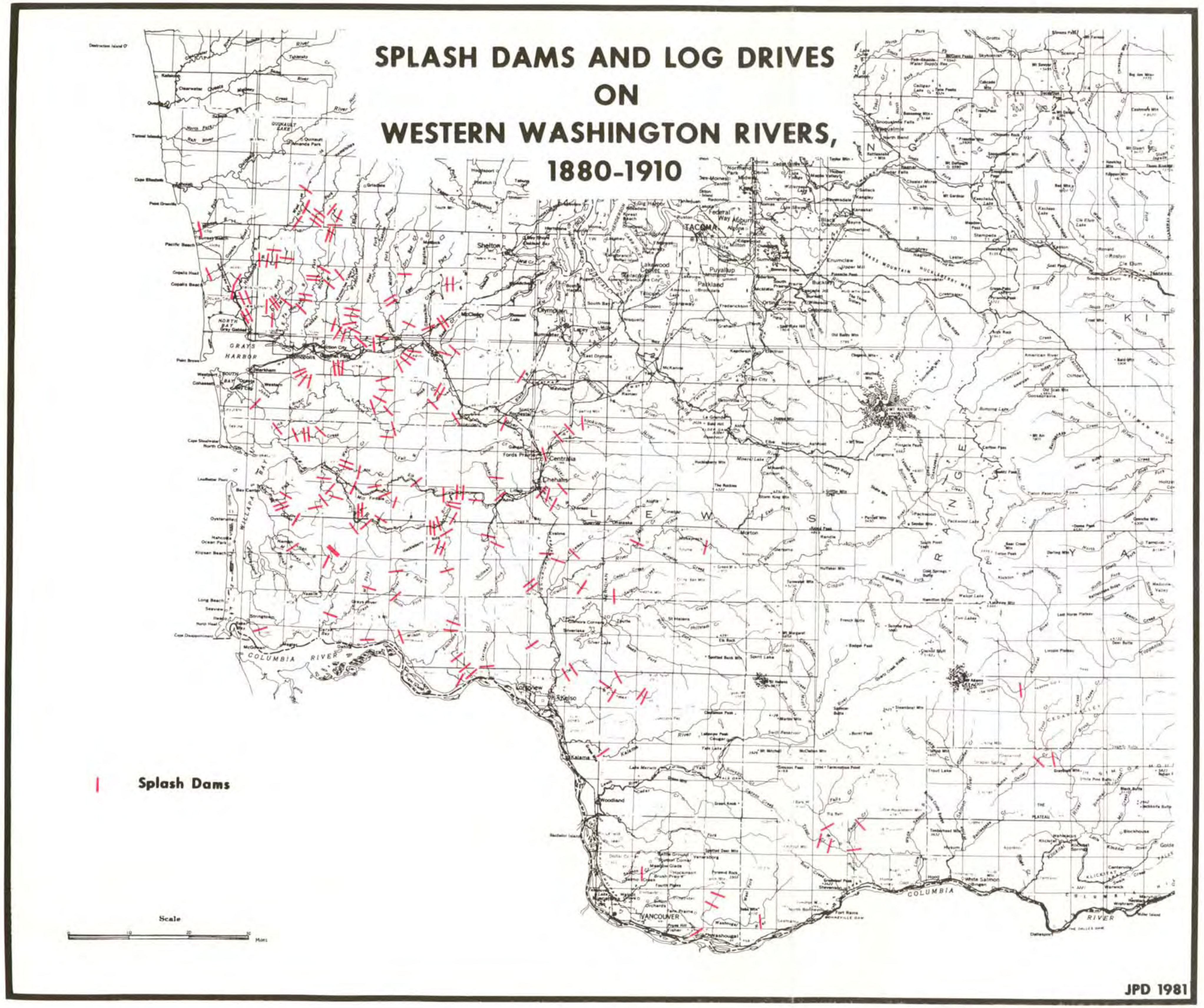


Figure 2.--Splash dams operating on western Washington rivers from 1880 through 1910 (from Bryant 1949, Wendler and Deschamps 1955, and U.S. Army Corps of Engineers reports on file at Portland District Office).

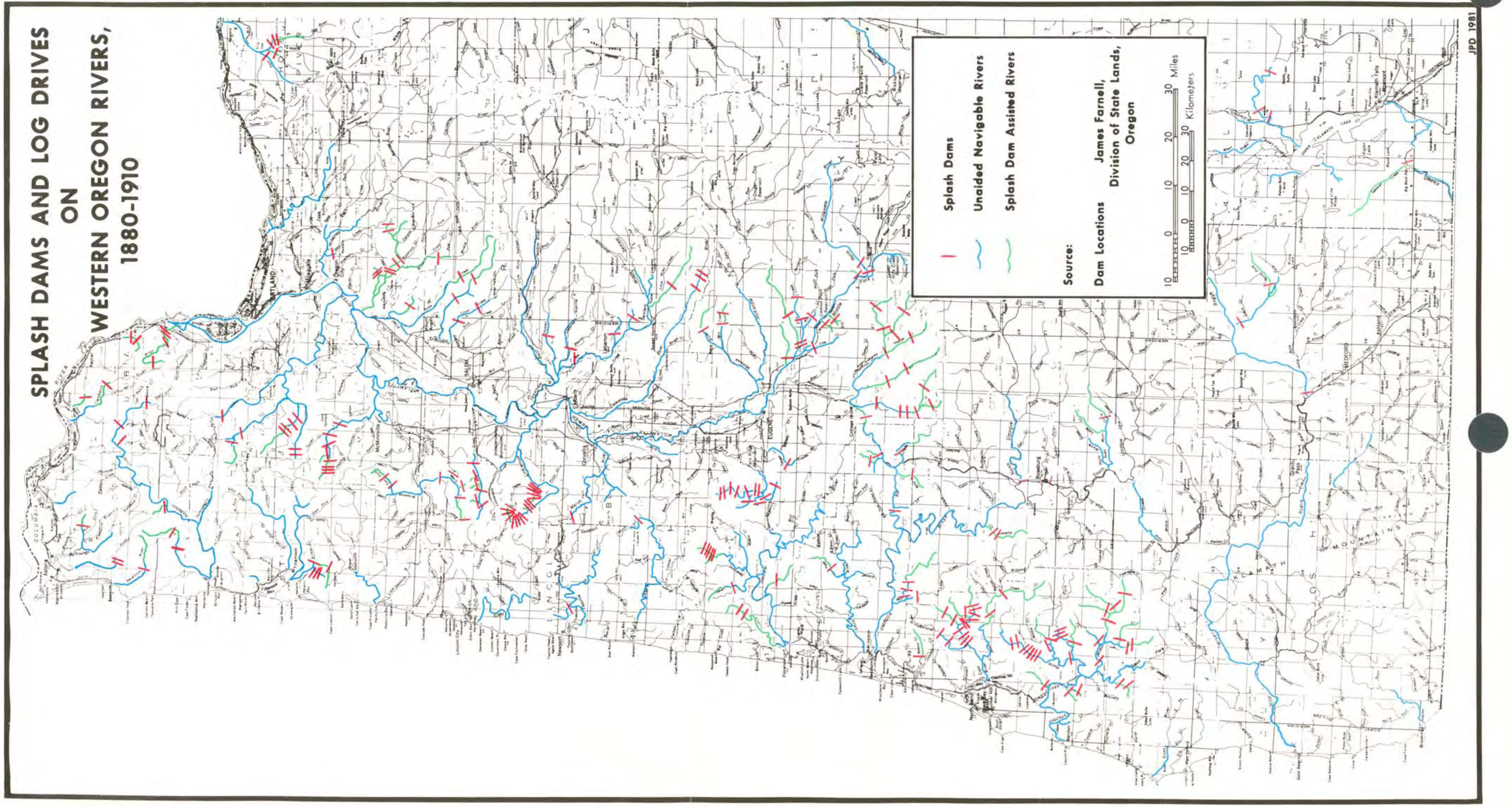


Figure 3.--Splash dams operating on western Oregon rivers from 1880-1910 (some on the Coos Bay rivers operated until the mid-1950's). Data were derived from research and reports by Dr. James E. Farnell of the Division of State Lands, Salem, Oregon.

were used seasonally, but no records were kept. Wendler and Deschamps (1955) were mainly concerned with these dams as obstacles to fish migration. Many were actually barriers, but the long-term damage was probably caused by the stream improvement before the drive and the scouring, widening, and unloading of main-channel gravels during the drive.

Small streams were heavily impacted by logging of cedar (*Thuja plicata* Donn ex D. Don), which occurred many years before clear-cut harvest. Because cedar was used for shingles and not just for lumber like Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), it could be cut up into small bolts (<1-m lengths). They could then be driven down very small streams. "By taking out shingle bolts from inaccessible localities far from the mills and driving them down streams impossible for logs, it is possible to utilize overmature cedar that would deteriorate before general logging on the tract was possible" (West Coast Lumberman 1914). Much of the best and most plentiful cedar timber occurred along streams in Puget Sound and in rich, moist, coastal valleys; it was exploited more rapidly than Douglas-fir. Even for driving cedar bolts, small streams had to be cleared of fallen trees, big boulders, and vegetation rooted in the channels. Streams were maintained clear of obstructions until the cedar logging in the drainage was completed.

To maintain unimpeded navigation of logs and commercial barges, snag boats operated on Puget Sound streams from 1890-1978. During this period, about 3,000 snags a year were removed from a total of 322 km of stream length in the Skagit, Nooksack, Snohomish, Stillaguamish, and Duwamish Rivers. In 1890, Coquille County in Oregon authorized a public snagging operation on the Coquille River system that continued until the early 1970's.

Clearing of streams and rivers for passage of boats and logs has reduced the interaction of the stream system with its flood-plain vegetation. Draining, ditching, and diking of valley bottoms and lowlands has also reduced terrestrial-aquatic interaction. Flood-control levees have reduced or eliminated complex sloughs and side channels, which are valuable rearing areas for salmonids (Sedell and others 1980).

River improvements and log drives on coastal Oregon and Washington rivers and rivers on the west side of Puget Sound strongly affected the estuaries. When large, natural debris dams were cleared out of the lower Nooksack in the mid-1880's, the resulting flush of channel sediments filled Bellingham Bay over a kilometer (U.S. Congress 1892). Sediments from cleanup activities transported by the Siletz River filled Siletz Bay between 1905 and 1923 (Rea 1975). River snagging resulted in an unloading of sediments from the main channel and a deposition in the bays below. All coastal Oregon and Washington rivers reflect a lack of improvements for log drives.

Along the arid west central coast of California, rivers and streams also supported log drives. In western Nevada, from 1853 to 1914, over 64 sawmills operated on sections that are now relatively treeless. Billions of board feet of timber were driven down the Truckee, Carson, and Walker River systems for lumber, firewood, and other uses related to the development of the silver mines around Virginia City (The Timberman 1941). Many of the mining and smelting activities in Arizona, Montana, Utah, and Colorado in the late 1880's depended on stream transportation of logs. The transcontinental railroads required large and continual supplies of railroad ties, which were not preserved with creosote in those days. The demand was met by logging watersheds adjacent to the railway and driving the logs down streams that intersected the line (Brown 1936).

The rivers in the more arid parts of the United States also had to be improved before log drives could begin. Marble Creek on the St. Joseph River in Idaho is one example. Blake (1971) described the numerous debris jams that had been there for many years. In a 29-km stretch ending at Homestead Creek, over 500,000 board feet of good timber were recovered from the stream channel. An additional large amount of wood was used to fuel the steam donkey's trip up the canyon to Homestead Creek. Blake and his companions also ". . . pulled over and sawed any trees standing on the bank which might fall and cause a jam while the drive was on" (p. 73). Fishing was described as excellent on this stream before the drives. "Fifteen minutes after we moved through a deep hole, we could catch 6 or 8 large trout there. I have never seen trout fishing, from Canada to California, half as good as the fishing on the Marble Creek before the log drives" (Blake 1971, p. 73). This is probably a "fish story" to some extent, but the fact remains that large trout were not there after the log drives.

In Alaska and western British Columbia, log drives were not common in the history of logging or stream degradation. Log drives in the Yukon, Chena, and Tanana Rivers and tributaries have been well documented; in particular, they supplied timber during the gold rush in the early 1900"s. Eraser River, British Columbia, tributaries were driven extensively from 1910 to 1946. A log drive in 1965 on the Stellako River was the only one ever studied from a fish-habitat point of view (international Pacific Salmon Fisheries Commission 1966).

All of these rivers had to be improved in one way or another. Blasting boulders and pulling debris and snags was usually all that was needed on the larger streams. Throughout the West, the story was the same: sloughs and backwaters were closed off, pools were filled, and pools above rapids were lowered by blasting. The gradients of the streams were evened out and habitat complexity was lost.

Ironically, the attitude of "river improvement" from the old log-driving days has been a common theme of fisheries management until recently. Debris-jam removal and snagging for navigation and fisheries reasons have resulted in the long-term loss of thousands of miles of streams in the western United States (Sedell and others 1982, Sedell and Luchessa 1982). River-salvage logging and snagging the lower ends of rivers in Oregon, Washington, and Alaska continue on a large scale today. The salvage results in loss of the habitat complexity essential for both spawning and rearing of salmonids. Many philosophies carried over from log transportation and navigation days need to be overcome if we are to have an effective plan for protecting salmonid habitat.

EFFECTS OF LOG DRIVING ON SALMON POPULATIONS

SCOURING AND FLOW MANIPULATION

During early development of logging in the Pacific region of the United States, log driving in many streams with insufficient flow required periodic releases of water from splash dams. These surges of water and logs eroded streambeds, gouged banks, straightened river channels, and prevented fish from spawning. Eggs previously deposited were subject to heavy losses by scouring and silting, or by the reduced flow when the splash dam was closed. In addition, rearing areas for stream-dwelling species—such as coho and chinook salmon and trout—were largely destroyed.

Over 150 splash dams were installed in the Gray's Harbor-Willapa Bay area of southwestern Washington alone (Sedell and Luchessa 1982). The effects of these operations on salmon runs were described by Wendler and Deschamps (1955, p. 2) as follows:

> The actual splashing of a dam affected fish in several ways. If fish were spawning, the sluiced logs and tremendously increased

flows would drive them off their nests. On the day prior to the splashing of one of the large Stockwell dams on the Humptulips River, an observer had noted a large number of steelhead below the apron of the dam. After splashing, no fish were seen, nor were any seen the following day.

Besides harming the fish, splashing often adversely affected the stream environment. Moving logs gouged furrows in the gravel, and the suddenly increased flows scoured or moved the gravel bars, leaving only barren bedrock or heavy boulders. New stream channels were constantly being created and the existing ones changed. If the sudden influx of logs into the stream below the dam caused a log jam, as often happened, dynamite or black powder was used to clear the obstruction. In those days the policy seems to have been that if two boxes of powder would suffice, four were used. On some areas below dams in the lower Humptulips region, an average of five boxes of powder a day were used to break up log jams. Great numbers of salmon and steelhead trout were reportedly killed by these blasts.

Dam operators have stated that fish runs reaching the dams were reduced within 3 to 4 years after the inital construction, and they recognized that splashing deleteriously affected spawning below the structure. When splashing was done because of economic conditions and flow was normal below the dams, operators claimed that spawning was more successful as evidenced by increased runs in the next cycle.

The streambed was gouged by logs even though flows provided by splash dams presumably were adequate for log transport. In addition to damage from periodic surges of water, the logs themselves appear to have contributed to streambed damage and the reported decline in salmon runs.

Similar logging practices were employed in western Oregon on all coastal streams. The Coquille River had ten logging dams and innumerable log jams were created by logging debris. "Splash dams in the Coos and Coquille systems, built for the purpose of sluicing logs down the rivers, blocked the salmon runs and eliminated the productivity of the streams above them. This practice has also resulted in the sluicing of the gravel and destruction of the spawning area below the splash dams" (Gharrett and Hodges 1950). A study of the effects of logging on coho salmon production of the Coquille River showed a significant relation between production of lumber in Coos County (in which most of the Coquille River lies) and the catch of coho salmon 6 years later; high lumber production was generally followed by a decrease in the catch (McKernan and others 1950). This relation did not exist in an adjacent county where logging was less extensive.

The history of sockeye salmon runs to Lower Adams River, tributary to the Fraser River in British Columbia, provides an exceptional example of the effects of log driving on salmon. A typical splash dam, operated at the upper end of the river, sent surges of water and logs over spawning grounds used by large numbers of sockeye. One early observer (Baldridge 1916) recorded the following impression of this operation:

> When I arrived at the head of Adams River, or the mouth of Adams Lake, I found a large dam across the river. I found a fish ladder in it, and it was in good shape. This dam is used for splashing thousands of logs down the river in such a manner that without doubt it causes a great destruction of spawn in the Adams River.

The operation of this dam was of considerable concern to the fishery overseer; he reported that even when he tried to avoid the adverse effects of sudden releases of water, considerable damage was done to spawning areas (Shotton 1926a). In the drive started on November 13, 1926, a special effort was made to keep the flow high enough to prevent logs from dragging on the gravel beds. By November 19, the pole drive (5,500 logs) had reached the lower end of the Adams River, and poles were raking the spawning areas so badly that the fisheries guardian is reported to have left the river in disgust. In a subsequent assessment of the drive, the overseer (Shotton 1926b) reported as follows:

> The last mile was the scene of many jams and this is where the most damage was done both by the men tramping over the shallows and the poles raking almost every foot of that part of the river. It is almost impossible for the Guardian or myself to estimate the amount of damage done as there is no practical way of making such an estimate. The time occupied in the last mile was seven days, that in itself gives you some idea of what damage was done.

Thompson (1945) concluded that manipulation of river flow by the dam had adversely affected the Adams River sockeye run and most probably had caused the decline in this run observed after 1913. Subsequent increases in the sockeye population and the shift in dominance from the 1925 to 1961 cycle to the 1926 to 1962 cycle were attributed to the return to normal flow conditions in 1922. Here again, distinguishing the damage caused by surges of water from that caused by logs gouging the river bed and driving fish out of the river was impossible.

Following a survey of the Lower Adams River and the splash dam in 1940, Bell and Jackson (1941) observed that:

> The effects of driving logs down a salmon stream are illustrated well in the Adams River. Bars and shallows are deepened and pools are filled due to gouging of the bottom. Curves on the course are straightened by the impact of floating logs and the stream tends to become a swift straight raceway of uniform depth and velocity. When driving ceases, the river begins a return to the natural conditions, but the process is slow. Eleven years later the Adams River still shows markedly the alterations due to the movement of logs.

Most of the splash dams were temporary, and were abandoned after timber in the immediate vicinity had been removed. Of the 139 dams reported in Washington, 53 washed or rotted out, and 44 were later removed at the expense of the fishery agencies (Wendler and Deschamps 1955). The Lower Adams River dam was removed by the International Pacific Salmon Fisheries Commission in 1945 after being unused for more than 15 years.

The modern method of transporting logs from the forests to mills or shipping points is by trucks, using public or private roads. As a consequence, log driving is no longer common. No log drives are occurring in the rivers of Washington or Oregon, nor in any California streams used for spawning. The Clearwater River in Idaho was used for log driving until the late 1960's, but little spawning (steelhead trout) takes place in the affected part of the river.

In its brief to the Sloan Commission on Forestry, the Department of Fisheries of Canada (Whitmore 1955) summed up the effects of log driving and concluded that driving in shallow rivers had caused extensive damage in the past and still remained a threat to the salmon fishery. In addition to the destruction caused by gouging of gravel spawning bars and resultant channel erosion, construction of so-called "river improvements" created further dangers to salmon spawning and incubation by disrupting the normal regime of the river. "Stranded logs may divert water flow from gravel bars, resulting in drying out of deposited spawn, or diversion of normal water flows from potential spawning areas" (Larkin and Graduate Students 1959).

BARK LOSSES AND DEPOSITS

Much of the bark on logs is knocked off during a drive, either by contact with the stream bed or bank, or by contact with other logs. About one-third of the bark was removed from logs driven down the Stellako River (international Pacific Salmon Fisheries Commission 1966). Vladykov (1959) reported that about 40 percent of the bark was removed during pulpwood drives in Quebec, and several tons of bark were deposited in some rivers each year. Because of this deposition, spawning areas may be reduced and rich food-production areas may be completely smothered. McCrimmon (1954) concluded Chat bark deposits not only reduce spawning area, but also destroy the shelter for salmon fry, making them more vulnerable to predators.

In northern British Columbia, logging was carried on during the winter when the ground was frozen and roads remained passable. Where water transport was to be used, logs were stored until the waterways were open. Although bark on these winter-cut trees was more securely attached than on trees cut in summer, it became waterlogged and was easily removed if the logs were stored in water. When dislodged, the bark sank to the bottom as observed on both the Nadina and Stellako Rivers (International Pacific Salmon Fisheries Commission 1966).

RIVER IMPROVEMENTS

Rarely can logs be driven down a river without some form of "improvement" at difficult spots to prevent permanent stranding or jamming. Even in a large river such as the Fraser near Quesnel, British Columbia, booms had to be constructed to direct logs away from certain areas (International Pacific Salmon Fisheries Commission 1966). In the Quesnel River, projecting rocks have been removed to prevent log jams, and some side channels have been closed to prevent loss of logs in shallow water. This practice was common on all rivers in Oregon and Washington from tne 1860's to the 1920's. In Washington, over 300 river- and stream-improvement companies were registered from 1898 to 1948. Over 75 percent of these companies were registered between 1898 and 1920. In the Stellako River, a new channel was made near the lower end of the river, diverting flow from the original channel and destroying spawning grounds in 200 to 300 m of river length. The new channel was reported never to have been productive; it changed the hydraulic structure and reduced the amount of suitable spawning ground for about 500 m upstream from the new channel (International Pacific Salmon Fisheries Commission 1966)•

The Department of Fisheries of Canada (1964) reported that channeling on the Kitsumgallum River, British Columbia, did not stabilize the river bed because, as the flow was directed from one place, it scoured others. During the log driving (now discontinued) on this river, the logging company continually made requests for further river improvements and, in some instances, had to repair or rebuild previous work.

Despite construction to facilitate log driving, stranding of logs remained a major problem. Concerning the Kitsumgallum River, the Fishery Officer reported: "... stranded logs that piled up on the spawning riffles changed the river flow and velocity on these bars with resulting scouring in some places and stranding in others" (international Pacific Salmon Fisheries Commission 1966).

Salvage of stranded logs is an inevitable feature of river log driving. Salvage may require river boats and manpower, dynamite to break up jams, or bulldozers to push logs back. into the river. Such operations cause breakdown of the river banks and gouging of the stream bed, as well as disturbances—sometimes lethal--to fish and eggs.

MAJOR PHASES OF LOG HANDLING IN THE COASTAL WATERS OF BRITISH COLUMBIA AND SOUTHEASTERN ALASKA

In both southeastern Alaska and western British Columbia, geography and lack of roads have required the use of coastal marine and riverine waters for log storage and transportation. Log-handling and storage facilities that require water are: log-transfer sites for individual timber sales; log-raft formation and storage areas near the timber sale; winter log-raft storage areas; and storage and sorting areas near the mill.

The major phases of log handling have been reviewed in detail by Boyd (1979). Duval and others (1980), and Forest Engineering Research Institute of Canada, Western Division (FERIC) (1980) for British Columbia and by Beil (1974) and Forest Engineering Incorporated (1982) for southeastern Alaska. The different methods used—as well as the economics of alternative methods of dumping, sorting, booming, and transporting—are fully discussed in these reviews.

Logs are transported from the land-water transfer site or "dump" to sorting and booming grounds. They are then towed in booms to storage areas or transported on barges to dumping sites. From barge dumping sites or central sorting sites, logs are sorted, boomed, and stored; they are then towed to mill storage sites and finally to the processing facility.

Many combinations of methods have been and can be applied to any of the four major log-handling processes.

DUMPING

Methods of dumping include:

- Vertical hoist method, such as A-frame, ginpole, and parbuckle.
- Crane.
- Equipment watering, using a cat, skidder, or front-end loader.
- Slide ramp.
- Cable carriage.
- Self-tipping barges.

BOOMING

Historically, many kinds of rafts and booms have been used. Two basic types are currently used:

- Flat raft—logs are stored and towed loose inside a series of channel boomsticks. These rafts cover about 0.4 ha. In Canada, the rafts are divided into sections each about 21 X 21 m; each section holds 15 to 101 thousand board feet. Rafts of up to 30 sections are common.

- Bundle booms—logs are bundled loosely with wire or metal bands. Bundles range from 3 to 45 thousand board feet and usually draw 1.5 to 2.5 m of water. The bundles are stored and rafted similar to the flat rafts. A raft of bundles contains a log volume of 300 to 600 thousand board feet.

Log bundling is the preferred method for reducing log losses and making the sorting process more economical and efficient.

STORAGE

Marine storage can be either intertidal, shallow, or deepwater. Logs are often stored near freshwater inflows to reduce shipworm infestation, although the degree of protection this technique affords depends on factors such as salinity, currents, storage time, and season. Reduced storage time is probably the most efficient means of reducing shipworm damage.

TRANSPORT

Methods of transport include rafting with flat rafts from which log loss is high and which is limited to calm inside waters, and rafting with bundles, which reduces log loss and is less limited by weather in exposed areas. Barging is a common method of transportation in British Columbia because barges can be operated year round in exposed areas and because high volumes of logs pass through few sites. These barges can be self-dumping, self-loading, or both, and the logs can be barged either loose or in bundles.

Barge-mounted cranes capable of handling 22 bundles of 88 tons each have been developed and should reduce barging and dumping of loose logs.

The principal activities that may affect the marine environment are limited by economic and operational requirements to lands that are adjacent to water and that have acceptable combinations of geophysical and morphological features. Duval and others (1980) summarized the typical location and required conditions for each phase of log handling. These conditions are indicated in table 1.

Table 1--Typical conditions for log handling on British Columbia coastal waters and adjacent land

	Minimum depth of water, meters			Estuaries			Bays and sheltered reaches			Exposed shoreline	
Log-handling phase	0-4.5	4.6-7.5	Over 7.5	Muddy shore 0-20% slope	Mud to gravel 20-40% slope	Rocky shore 40-80% slope (deep water)	Tidal marshes Muddy shore 10% slope	Gravel shore 10-40% slope	Rocky shore 40-60% slope (deep water)	Gravel 10-20% slope	Rocky 20-50% slope (deep water)
Skidding (not common)											
Skidding onto beach	X				X			X		X	
Yarding into water						X			X		
Tractor pushing					X			X		X	X
Dumping											
Lift and lower bundles	X	X		X		X		X			
Lift and lower loose logs		X		X		X		X			
Parbuckle onto log, skids bundles		X		X	X	X	X	X	X		
Parbuckle onto log, skids loose logs	X	X		X	X	X	X	X	X		
Mobile loader over skids bundles		X			X	X	X	X	X	X	X
Mobile loader on gravel ramp, loose logs	X	X			X			X		X	
Helicopter drop			X			X			X		X
Sorting in water											
Loose logs		X			X		X	X			
Loose logs to make bundles		X			X			X			
Bundles			X		X						
Booming											
Bundle booms		X					X	X			
Flat rafts		X					X	X			
Bag booms		X					X	X			
Storage											
Bundle booms		X					X	X			
Flat rafts	X	X					X	X			
Bag booms	X	X					X	X			
Dry-land sort					X			X			
Barge loading and dumping											
Loose logs					X			X			
Bundles					X			X			
Transporting											
Bag booms	X	X		X	X	X	X	X	X		
Flat booms	X	X		X	X	X	X	X	X		

PHYSICAL IMPACTS OF LOG HANDLING

LOG DUMPING

Physical disturbances resulting from log dumping include substrate disturbances in areas where the logs contact the bottom, deposition of bark and wood debris and subsequent dispersion, deposition of other debris (for example, bundling bands) associated with the log handling, and loss of whole logs through sinkage. The magnitude and spatial extent of these disturbances differ greatly with the type of log dump, the depth of the water column, geomorphology and substrate composition at the dump site, log species handled, age of logs, the season and volume of the operation, and prevailing current and circulation patterns.

Consequently, the amount of substrate disturbance and debris accumulation differs among log-dump sites. Because log sorting, booming, and storage activities frequently occur in conjunction with dumping, distinguishing physical impacts resulting from different log-handling activities is difficult. Quantitative information describing some of these physical disturbances is limited.

SUBSTRATE DISTURBANCES

No data are available on the effects of log dumping on bottom substrates, although the Ministry of Environment, British Columbia (1976), in a report dealing with Ladysmith Harbour, suggested that scouring could result when logs are dumped by free-fall methods into shallow water. Because qualitative and quantitative data are lacking, we can only discuss substrate disturbances likely to result from log dumping.

The method of log dumping, water depth, and location of each site are the major factors influencing the degree of substrate compaction, scouring, or both. Of the basic methods of dumping, the least substrate disturbance would result from "lift and lower" and helicopter dumps, providing these activities did not occur in intertidal areas—particularly at low tide. On the other hand, parbuckle dumps and any form of skidding could cause more bottom disturbance, particularly in shallow water. Because log dumps remain in a single location while logging goes on in a particular area, substrate disturbances are likely to be localized except where more widespread accumulation of bark requires periodic dredging of larger areas. The greatest disturbance of substrate could result from barge dumping if logs Couched the bottom in shallow water. Because barge dump sites must be located in areas with sufficient water depth to allow passage of large tugs, however, substrate disturbances from this activity are probably minimal.

The amounts of substrate disturbance resulting from dumping of bundled and loose logs are also likely to differ. The proportions of logs that are dumped loose or in bundles differ markedly by region. For all of coastal British Columbia, about 69 percent of the cut is bundled before dumping (FERIC 1980). In southeastern Alaska, over 99 percent of the timber cut is dumped as bundles (Paris and Vaughan 1985). Because bundled logs sink deeper before floating, a greater potential exists for contact with the bottom. As in all forms of dumping. However, this would cause substrate disturbances only if the dump site were in shallow water.

BARK. DEPOSITION AND DISPERSION

The deposition of bark and wood fiber at log dumps has been examined or discussed by several authors, including Conlan (1975, 1977); Ellis (1973); Ministry of Environment, British Columbia (1976); Pease (1974); Schaumburg and Walker (1973); and Schultz and Berg (1976). Four log dumps in coastal Alaska were examined during SCUBA surveys conducted by Ellis (1973); three of these dumps had been abandoned for 2 years or more. The divers observed bark and wood deposits at each site, with considerable variability in the depth of debris accumulation. One inactive dump site was characterized by only scattered deposits of decomposing wood and bark debris in depressions in the sea bottom in water up to 10 m deep. At another site, accumulations of debris were "several feet deep, black and foul, and obviously anaerobic." Debris accumulations were noted at water depths up to 23 m at two log dumps, and at one site the effects of dumping were evident for about 45 m on either side of the center of an abandoned dump (Ellis 1973), forming a pattern similar to a stream delta.

Studies of bark deposition in the Yaquina estuary in Oregon were conducted by Schaumburg and Walker (1973). Although the authors did not examine the spatial extent of debris accumulation, they reported that both mean particle size in the sediments and the proportion of organic solids were larger in areas of log handling. Three active and five abandoned log dumps in southeastern Alaska were examined in detail by Pease (1974). Benthic bark deposits were observed at all active and abandoned dump sites, but only scattered deposits were observed in log-storage areas. The depth of bark deposition was at least partially related to the period of activity of the dump site, the volume of logs handled, or both. One site that had been active for 10 years had bark deposits 60 to 90 cm deep, but only 5 to 8 cm of bark were found at a dump that had been active for 1 year. Ellis (1973) found a similar correlation between the depth of bark deposition and period of use at other southeastern Alaska log-dump sites. Pease (1974) also noted that the area of substrate covered by bark differed between active and abandoned sites. At the oldest (7 to 10 years) active dumping sites, the bark-covered area extended a radius of at least 60 m from the point where log bundles were introduced into the water. At the sites that had been abandoned for 1 to 11 years, this radius was reduced to about 15 to 23 m. Scattered patches of white powder were observed on the bark at many of the dump sites; Pease suggested that this material was either magnesium or calcium sulfide. Bark deposits may trap silt particles transported from adjacent areas or introduced into the water column with the logs. Silt accumulations in bark deposits have been documented by Ellis (1973) and Pease (1974).

Log-transfer facilities at 32 sites in southeastern Alaska were studied by Schultz and Berg (1976). The bark coverage in front of each transfer facility was observed using SCUBA. The locations of bark accumulations were plotted on maps, and the areas of coverage were calculated. For 31 of the sites, the areas covered by bark ranged from 0 to 3.7 ha. Paris and Vaughan (1985) recalculated Schultz and Berg's (1976) data and obtained an average of about 0.8 ha of bark accumulation for the 31 observations, with a mode of 0.4 ha. At 13 sites, no measurable accumulation of bark or debris was found directly around the site. Presumably, the debris generated during transfer was transported (by gradient, currents, or tide) to deeper water, covered by sediment, or decayed. Faris and Vaughan concluded that conditions at each of the log-transfer locations were too variable to generalize about where and how much bark and debris would accumulate. More recently, Conlan (1977) examined the distribution of bark debris around an active dump site and an abandoned dump site at Mill Bay, British Columbia. She reported that bark was deposited over an area of about 1 km^2 at each site. The deposits were thickest (>15 cm) close to the dumps, and thinned with increasing distance from the area. Considerable bark persisted at the site, which had been abandoned for 20 years, corroborating the observations of Ellis (1973) and Pease (1974) that dispersal of debris was slow from areas with poor water circulation. None of these studies measured currents directly, but inferred poor circulation based on the remaining deposits.

Other authors have discussed the fate of bark debris at dump sites and factors influencing the amount of deposition. Conlan (1975) suggested that decomposition of wood at dump sites would require 20 years or more; she cited studies conducted in a coastal lake in Oregon by Hansen and others (1971), which showed that bark debris was still evident after 30 to 40 years. Subsequent studies by Conlan (1977) confirmed the presence of bark deposits at a log dump at Mill Bay, British Columbia, that had been abandoned for 20 years.

Sctiaumburg (1973) studied the effects of log species handled and method of dumping on the amount of bark loss, and found that 17 percent of Douglas-fir bark was lost during dumping of loose logs, compared to about 6 percent for ponderosa pine (Pinus ponderosa Laws.), which has more tightly bound bark (table 2). Schaumburg (1973) also examined the effect of dumping method on bark loss by Douglas-fir, and reported average losses of 17 percent for slide-ramp (parbuckle) and 7 percent for A-frame hoist (lift and lower) methods.

Table 2—Incremental percentages of bark dislodged during "logging, unloading, and raft transport (from Schaumburg 1973)

	Percent			
Species	During logging	During unloading	During raft transport	During unloading and transport
Douglas-fir	18.2	16.8	4.9	21.7
Ponderosa pine	5.7			6.2

-- = no data available.

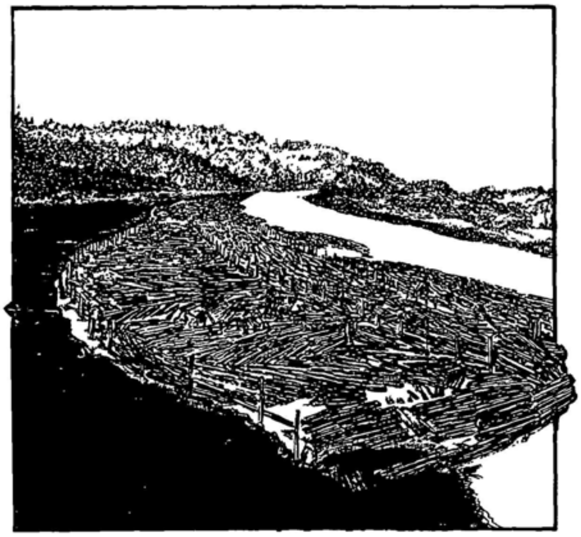
Sinking rates and dispersion of debris from log dumping are related to bark particle size. In experiments conducted on Douglas-fir bark, Schaumburg (1973) reported that smaller pieces of bark sank first, and that 10, 47, and 75 percent of the bark had sunk after 1, 30, and 60 days, respectively. Water currents near a dump site influence the pattern of bark deposition in two ways; while the bark remains afloat, it can be distributed over the water surface by currents and wind; once the bark sinks, its distribution may be subsequently altered by subsurface currents. Ellis (1970), in a study of three active dump sites in southeastern Alaska, found that water currents affect the extent of bark deposition. Although these dump sites had been used for 12 years, no bark and wood debris had accumulated, probably as a result of the strong currents in the area. Bundling of logs before dumping has been suggested to result in less bark loss (Conlan 1977; Hansen and others 1971; Ministry of Environment, British Columbia 1976), although bark loosened during preparation of the bundles and dumping may remain within the bundle and be deposited in areas where the bundles are broken.

In summary, bark deposition is a characteristic of most log-dumping areas that have been examined. Some methods of dumping and some species of logs result in greater bark losses. The limited data also suggest that the intensity of the operation and period of use of a dump site affect bark accumulation, and that deposits sometimes attain depths up to 90 cm (typically much less) and cover areas up to 1 km^2 around the dump site. Further study is needed, however, to provide information for planners on the mechanics of bark dispersal.

DEPOSITION OF OTHER DEBRIS AND LOG SINKAGE

Sunken logs and accumulations of inorganic debris have been observed at several log-dumping sites (Conlan 1975, Ellis 1973, Pease 1974); however, quantitative data on deposition of debris other than bark are lacking. Inorganic debris observed in waters adjacent to coastal log-dump sites in British Columbia and southeastern Alaska has included old cables, bundle straps, bottles, head gaskets from an engine, a cast-iron stove, an abandoned bulldozer, and other refuse. Wood shavings from boomstick boring have also been found at several sites (Pease 1974). The most prevalent type of debris is bundling straps, which are likely to decrease in the future because some operators now use wire cables that can be re-used.

Some logs have a specific gravity greater than 1.0 and sink immediately when dumped; others sink during storage once they become permeated with water. Waeiti and McLeod (1971) reported that hemlock (Tsuga heterophylla (Raf.) Sarg.) logs were most susceptible to sinkage, and British Columbia Research Council (1964) showed that 1.1 percent of hemlock logs tested sank immediately. In this study, sinkage after 4, 11, and 28 weeks increased to 2.8, 4.1, and 9 percent, respectively, with the greater proportion of sinkers coming from hemlock harvested during the spring. Salvage operations are generally initiated where accumulation of sinkers hampers the movement of log dozers or other aspects of the log handling. The bundling of logs before watering, however, has greatly reduced log sinkage.



LOG STORAGE

Log storage results in substrate disturbances in intertidal storage areas, leads to deposition of bark and wood debris, causes loss of logs through sinkage when logs are stored in flat rafts, reduces wave action, and decreases light penetration. Several of these physical impacts are also observed during log dumping, but log storage differs in either spatial extent or magnitude. The literature on the physical impacts of log storage is more extensive than on log dumping, and includes studies conducted in British Columbia, Washington, Oregon, and southeastern Alaska.

SUBSTRATE DISTURBANCES

Log storage can result in compaction or scouring of substrates when logs are stored in intertidal areas or shallow water. Ellis (1973) conducted SCUBA surveys under floating log rafts in Hanus Bay, Alaska, and was unable to distinguish any differences in the substrate character from those observed in a control area. Grounding of rafted logs in shallow intertidal areas, however, has been shown to result in significant disturbances to the substrate. For example. Pease (1974) reported that in an intertidal log-storage area, portions of the bottom had large depressions and were compacted to the consistency of sandstone by the action of log bundles grounding at low tide. Similar observations have been made in the estuaries of the Squamish River, Washington (Levings and McDaniel 1976); Nanaimo River, British Columbia (Sibert and Harpham 1979); and Snohomish River, Washington (Smith 1977). In the first study, sediments on beaches were disturbed by abrasion and scouring from resting logs at low tide, disruption from towing the logs on or off the beach, or both. Sibert and Harpham (1979) examined the substrate under an intertidal log-storage area in the Nanaimo River estuary where both flat raft and bundle booms were present. The bottom was characterized by grooves (up to 15 cm deep), parallel to the stored logs. These sediments were also compacted and the redox-potential discontinuity layer was located closer to the sediment-water interface than in areas unaffected by log storage. Sibert and Harpham (1979) suggested this discontinuity layer resulted from reduced circulation of interstitial water. They also noted that movement of bundle booms by tugs contributed to substrate scouring and subsequent release of hydrogen sulfide. Smith (1977) also noted the presence of troughs and ridges caused by grounding of logs in the Snohomish River estuary, Washington.

The potential for disturbance of intertidal substrate during log storage is highest with bundle booms because of their greater draft, although substrate disturbances resulting from log sinkage are simultaneously minimized by bundling of logs. Some operators, however, locate storage facilities in sheltered areas with sufficient water depth to prevent grounding of bundles or flat rafts at all times.

BARK DEPOSITION AND DISPERSION

The abundance and distribution of bark and woody debris under log-storage areas has been intensively investigated. Most studies have shown that bark accumulation in areas used for log storage is considerably less than in areas used for log dumping, although water circulation patterns also influence the degree of bark accumulation (Pease 1974, Sibert and Harpham 1979). For example, Sibert and Harpham (1979) found bark and other debris in pits and depressions under log booms, but the accumulations were localized and relatively small. Sediment particle size was smaller and organic content was higher in sediment samples collected under log booms than in control samples. These trends were previously observed under logs stored in the Yaquina River estuary on the central Oregon coast (Schaumburg and Walker 1973).

OTHER PHYSICAL DISTURBANCES

Other impacts include log loss from sinkage, reduction of wave action, decreased light penetration when suspended wood fibers are present in the water column, and shading of the substrate. Loss of logs from sinkage does not generally occur during storage when bundles are used (Conlan 1975, Pease 1974). In areas of flat-raft storage, log sinkage can subsequently affect benthic invertebrate communities, increase available habitat for shipworms (Bankia setacea Tyron), and result in the proliferation of fungal and bacterial decomposers (Conlan 1975).

Conlan (1975) suggested that log rafts in storage may reduce wave action and therefore increase rates of silt and log-debris sedimentation. Although quantitative data to assess this area of impact are limited, observations by divers under log rafts stored in the Nanaimo River estuary indicate that logs stored intertidally act as silt traps for materials transported by the Nanaimo River.

Conlan (1975) suggested that log dumping and storage decrease light penetration as a result of scattering by suspended wood fibers and shading. Although this decrease probably occurs, neither effects of suspended debris and rafted logs on light intensity nor the spectral composition of available light have been measured.

LOG SORTING AND TRANSPORT

No quantitative data are available that distinguish the physical and chemical impacts of water sorting and transport of logs from effects of log dumping and storage. Some impacts can nevertheless be suggested from study-team observations. Because water sorting with log dozers (British Columbia term) or boom boats (U.S. term) involves repeated and often vigorous contact with logs, considerable loosening and deposition of bark can be expected. Log dozers also create turbulence in the water column from propeller wash, which could disturb the substrate in shallow sorting grounds and contribute to release of hydrogen sulfide in decomposing wood and bark debris, as well as scatter the bark. Log sinkage in sorting grounds undoubtedly occurs, particularly when bundles containing hemlock are broken down for further sorting.

The only potential sources of physical impact during log transport outside booming and storage grounds are log losses either from sinkage from flat-raft booms or from loss or breakage of entire booms during adverse weather or rough seas. When salvage operations are undertaken to recover lost logs, physical impacts to shoreline areas are relatively short term and minimal.

Movement of logs by tugs in shallow estuarine areas can result in both debris accumulation and substrate scouring. For example, tug propeller wash during transport of flat rafts and bundle booms in the Nanaimo River estuary has resulted in substrate scouring to depths ranging from 0.5 to 1.5 m, although these scoured areas gradually fill in with sediments transported by the river (Fish Habitat and Log Management Task Force 1980). Grounding of bundle booms during towing in this estuary contributes to additional scouring, and breakage of bands, cables, or both on impact with the bottom is responsible for accumulation of these strapping materials on the substrate.

DEBRIS ACCUMULATION

The debris resulting from log handling also includes lost logs that remain afloat and subsequently become stranded along shorelines, and deadheads or low floaters that may also accumulate on beaches or eventually sink.

Waeiti and McLeod (1971) estimated that 680 000 m^3 of logs were lost annually in the coastal Vancouver Forest Region. The volume of natural debris (as well as debris other than logs from log handling) has not been well documented. On some beaches, up to 90 percent of the debris has cut ends, indicating they originate from logging or construction. In southeastern Alaska, most woody debris on the beaches is natural (Beil 1974, Forest Engineering Incorporated 1982). Council of Forest Industries (1974, 1980) estimated that gross log losses (including sinkage, but excluding recoveries by the British Columbia Log Spill Recovery Association) amounted to 827 000 m^3. Roughly 40 percent of these losses were eventually recovered by log-salvage permitees and others, another 35 percent (chiefly hemlock) sank, and the remaining 25 percent were lost to beaches or the open sea.

Evans (1977) noted that the greatest proportion (about 70 percent) of wood debris in Georgia Strait resulted from log-handling losses on the inside waters of the British Columbia south coast (table 3). Hemlock (particularly smaller logs) was always the main species lost. Recent moves by some companies to increase dry-land sorting, water bundling, or both, have greatly reduced flat rafting and associated log losses.

Council of Forest Industries (1974) estimated log losses by species and log size for each of four basic handling methods (table 4). The accumulation of these materials on beaches has been discussed by Waeiti and MacLeod (1971). These authors reported that gently sloping beaches accumulate the most debris, and rocky, steep shorelines trap relatively few logs. Waeiti and MacLeod (1971) suggested that beach debris can be classified into three age groups: transient material lying below average high tide, which may be naturally removed within one change of tide; material lying above average high tide ("new drift"), which is subject to dislocation and drift to another area during extreme tides; and "old drift" deposited permanently above and behind high tide by extreme tides and winds. They emphasized that the second category of material comprises the bulk of the beach wood, and the third category is generally old and at least partially decomposed.

Table 3—Sources of logs and debris and estimated volume in Georgia Strait (from Evans 1977)

Source	Volume of logs and debris
	Cubic meters
Log transport and storage	297 000
Mills on Burrard Inlet and the Fraser River	42 000 to 85 000
Howe Sound sorting	6 000 to 11 000

Table 4—Estimated log losses for each of 4 basic handling methods (from Council of Forest Industries 1974)

Log-handling methods	Portion of production in 1974	Losses
	Percent	
Dry-land sort and bundles, direct trucking to mills, or both		0.33
Water-bundled before towing to mills		1.7
Dump, sort, and flat-raft transport to mills		3.2
Barging of loose logs, dumping, and flat-raft transport to mills	22	6.1

CHEMICAL IMPACTS OF LOG HANDLING

The major chemical impacts of log handling are increased biochemical oxygen demand (BOD), hydrogen sulfide and ammonia production during the decomposition of bark and woody debris, and the release of soluble organic compounds (leachates) from logs. When present in sufficient quantities, leachates also exert an oxygen demand on adjacent waters and impart a yellow to brown color to the water. The literature describing the chemical impacts of log handling is extensive.

DECOMPOSITION OF BARK AND LOG DEBRIS

The decomposition of bark and wood debris in water is comprised of two phases. The first phase is a relatively rapid process mediated by heterotrophic bacteria; the second phase is slower, requiring lignin-decomposing fungi, which are common in terrestrial ecosystems but not in marine environments. Decomposition in this slower phase, however, is often augmented by boring organisms—that is, *Bankia setacea* and *Limnona lignorum*--which increase fungal access to the interior of the wood.

Decomposing bark and wood in the water column and on the substrate both create a biochemical oxygen demand. The oxygen demand of wood debris suspended in the water column is insignificant, however, if currents are greater than 0.01 m/sec (Pease 1974), which is generally true in surface waters under the influence of tidal currents. FERIC (1980) reported that tidal currents in 47.3 percent of the log-handling lease areas in coastal British Columbia were negligible; thus, BOD in the water column may be higher than normal in some areas. BOD becomes a measurable and significant process at the water/sediment interface, where circulation of oxygenated interstitial water may be reduced and bark deposits may accumulate.

INCREASED BIOCHEMICAL OXYGEN DEMAND

The oxygen uptake of benthic bark deposits has been measured by McKeown and others (1968), Pease (1974), and Schaumburg (1973). These authors reported oxygen demands from 0.2 to 4.4 g 0/m- per day, depending on ambient conditions. Schaumburg (1973) found that the oxygen demand of bark deposits in Oregon coastal waters increased with the concentration of organic solids in the deposits and increased surface area of the log debris. He also indicated that oxygen demand was not related to the depth of bark deposits. Ponce (1974) also demonstrated a relation between oxygen demand and distribution of log—debris particle size and surface area. McKeown and others (1968) indicated that mixing or water turbulence above the substrate increases the oxygen demand of benthic bark deposits by accelerating decomposition. Uptake ranged from 0.2 to 0.8 g $0/m^2$ per day under stagnant conditions, but water movement above the deposits increased the demand to 2.7 g $0/m^2$ per day. Gentle scouring of the benthic bark deposits further raised the oxygen demand to 4.4 g $0/m^2$ per day.

INCREASED HYDROGEN SULFIDE CONCENTRATIONS

With the exception of beaches exposed to a strong surf, marine sediments are generally anaerobic and chemically reducing beneath a relatively thin oxidized layer (Fenchel and Riedl 1970). Consequently, degradation of wood and bark debris in estuarine and marine sediments is primarily through sulfate reduction. This bacterially mediated process results in production of hydrogen sulfide, various organic compounds, and carbon monoxide. Hydrogen sulfide reacts with soluble iron in interstitial waters to form ferrous sulfide (FeS), although phosphate also competes with sulfides for available iron in interstitial waters. When the available iron is used or its rate of use exceeds that supplied to or regenerated within the sediments, additional free sulfides exist within the interstitial waters, and pyrite-which is formed from ferrous sulfide--becomes an irreversible sink for available iron. The formation of pyrite decreases the total sulfide capacity and increases the probability of free sulfide formation (Bella 1975). The tendency for the leached extracts from bark and debris deposits to exhaust the iron in surface sediments is evident from the high concentrations of free hydrogen sulfide present in benthic wood deposits (Pease 1974).

Within undisturbed sediments, the FeS content increases as available organics are decomposed, and as long as the FeS content does not approach the total sulfide capacity, free sulfide will not be formed. Physical disturbance or flushing of the sediment with aerobic waters will oxidize the FeS and release the sulfide. Then, the sediments undergo a series of cycles in which the FeS increases during the periods of physical stability and rapidly decreases during sediment disturbance. Such disturbances have been observed in the Campbell River and Nanaimo River estuaries as a result of tug-boat propeller wash during log handling (Sibert and Harpham 1979, Vigers and Hoos 1977). During both of these studies, hydrogen sulfide concentrations were not measured, but were detectable by smell. Bubbling of hydrogen sulfide from benthic bark deposits has also been documented at coastal British Columbia log dumps.

If bark and debris in log dumping, sorting, and storage areas represents a biodegradable organic source that exceeds the available iron capacity, then the conversion of all available iron to iron pyrite assures the continued production of free sulfide. Conlan (1975), however, cited only one instance when resultant hydrogen sulfide concentrations reached toxic concentrations, which occurred when organic matter was buried under beach gravel (Hansen and others 1971). Other laboratory studies with fish have shown that acute lethal concentrations of hydrogen sulfide have ranged from 0.8 to 7.0 mg/liter depending on test species and pH (U.S.

Environmental Protection Agency 1971). No quantitative information is available, however, to indicate the increase in hydrogen sulfide production from log debris is above that normally associated with decomposition in marine sediments.

WOOD LEACHATES

Significant quantities of soluble organic compounds are released by logs stored in water as well as by submerged bark deposits (Conlan 1975). The character of these leachates depends on the tree species, but it generally includes tannins, resins, oils, fats, terpenes, flavanoids, quinones, carbohydrates, giycosides, and alkaloids (Wise 1959). The tannin, flavanoid, resin, and quinone components are primarily responsible for the yellow to brown color associated with leachates, and each of these components contributes differently to oxygen demand (Schaumburg 1973). Leaching is faster in salt water than in fresh water, and the rate of leaching decreases as the quantity of soluble organics in surrounding waters increases. In flowing water, the leaching process is nearly constant for at least 30 days (Hansen and others 1971).

Schaumburg (1973) reported that 60 Co 80 percent of the solids leached from wood are volatile, although the rate of leaching varies with the flushing rate, species and age of wood, time the wood or bark has been in the water, and temperature (Atkinson 1971, Gove and Gellman 1971). Gove and Gellman (1971) also noted that the greatest proportion of leachate was released from the cut ends of logs and the bark. Although in-place leaching rates may be quite different. Pease (1974) ranked tree species according to their leaching rates (from highest to lowest, as follows: western redcedar (Thuja plicata Donn ex D. Don), Alaska-cedar (Chamaecyparis nootkatensis (D. Don) Spach), western hemlock (Tsuga heterophylla (Raf.) Sarg.), and Sitka spruce (Picea sitchensis (Bong.) Carr.).

Conlan (1975) has suggested that the yellow to brown color imparted to surrounding waters by leachates could affect light penetration and thus algal growth. The increased chemical oxygen demand (COD) resulting from log leachates has been examined by Schaumburg (1973), who reported a decrease in the COD of Douglas-fir leachate from 0.46 to 0.07 g/m^2 per day after 25 to 30 days.

A major concern about leachates is their potential toxicity to marine and freshwater flora and fauna. Various authors, including Conlan (1975) and Pease (1974), have noted that the toxicity of leachates in seawater is negligible because of the tendency of lignin substances to precipitate in complex with chloride ions. Therefore, the greatest potential for adverse effects of leachates to biological resources would be near freshwater log-handling sites, although benthic micro flora and micro fauna may be adversely affected by precipitates formed in marine waters. At the same time, however, some of the organic constituents of leachates, such as glucose, may be beneficial to some species.

SUMMARY OF PHYSICAL AND CHEMICAL IMPACTS

The physical and chemical impacts of log handling depend primarily on the location and areal extent of the operation, the volume and species of logs handled, the activities occurring at the site, and particularly the local current patterns and intensity. The impacts of all phases of log handling are greater when activities affect intertidal areas. The most significant effect of log dumping is the accumulation of bark and wood debris on nearby bottom sediments. This form of physical impact is most pronounced with free-fall (nonmechanically controlled) dumps in areas of poor circulation. Other significant impacts of some log-dumping operations include substrate scouring or compaction and loss of logs through sinkage. Secondary or subsequent impacts are chemical and associated with release of hydrogen sulfide, increased BOD during decomposition of accumulated bark and wood, and the release of wood leachates, which also exert COD.

Log storage results in many of the same physical and chemical impacts as log dumping, as well as additional effects related to shading of the substrate in shallow water, reduced wave action, and a potentially greater opportunity for release of leachates when logs are stored for extended periods. Less bark and wood debris deposition is assumed to result from log storage than from dumping, but substrate compaction and scouring can be greater when logs are stored in intertidal areas. Log sinkage in storage grounds is minimized through use of bundle booms, although this practice may intensify impacts related to log grounding in intertidal areas. Silt also sometimes accumulates in estuarine log-storage grounds.

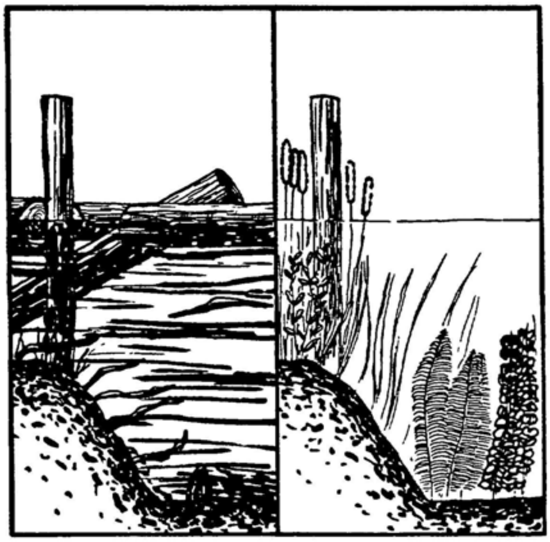
The most significant impact of log sorting is the release of additional bark and wood debris, although log dozers working in shallow waters can also contribute to substrate disturbance. Log transport only results in significant physical impacts when activities take place in shallow estuarine areas. Then, extensive substrate scouring can result from the propeller wash of tugs.

DATA DEFICIENCIES

Deficiencies in data on the physical and chemical effects of log handling are only important as they limit subsequent assessment of impacts to biological resources. Specific deficiencies are:

- Data describing the extent of substrate disturbance resulting from various methods of log dumping, particularly in shallow waters.
- Quantitative information on differences in substrate disturbance and bark deposition associated with dumping and storage of loose compared with bundled logs.
- Species-specific information describing rates of bark decomposition and dispersal under different flushing conditions.
- Measurements of light intensity and turbidity at various depths below stored log booms and at various distances from log-dump sites.
- In-place measurements of biochemical oxygen demand, chemical oxygen demand, hydrogen sulfide concentration, and leachate concentration in interstitial waters affected by wood and bark debris, as well as at various depths in the water column in poorly flushed areas.
- Bark loss between various entry systems.

- Bark loss between entry, booming, and storage operations.
- Threshold water-current rates that ensure bark dispersal.
- Relations between bark loss and species and age of logs.



IMPACTS OF LOG HANDLING ON PLANT COMMUNITIES

Impacts on plant communities may result from scouring of both hard and soft substrates, compaction of soft substrates, shading and other alterations in the light environment, deposition of bark and wood debris, and toxic or sublethal effects associated with increased oxygen demand and release of log leachates (Bell and Kallman 1976b, Conlan 1975). Although several authors have discussed the impacts of various phases of log handling on plants, no quantitative data and only a limited amount of observational information are available describing these impacts. Despite this apparent lack of published information, damage to emergent vegetation in particular is clearly evident in many coastal areas used for log handling (Duval and others 1980).

SUBSTRATEDISTURBANCES

Substrate disturbances may occur during log dumping, sorting, transport, and storage, but generally only when these activities take place in intertidal waters. Physical disturbances to substrates may also result when lost logs become stranded along shorelines and on beaches. Because quantitative data describing the impacts of these physical disturbances on plant communities are lacking, this section discusses qualitative observations of various authors, as well as potential impacts on plants based on known types of substrate disturbance resulting from log handling.

Several authors have observed or suggested impacts on plant communities resulting from the scouring or compaction of substrates by rafted logs. Bell and Kallman (1976c) reported that logs stored in the Nanaimo River estuary had adverse impacts on the eelgrass (Zostera marina L.) meadows as well as on the macrobenthic and microbenthic algae, but did not provide details regarding the type and extent of this damage. The earlier reports of Narver (1972) and Trethaway (1974) suggested that either propeller wash or dragged logs had resulted in gouging of the substrate in and near the larger eelgrass beds in the Nanaimo estuary. Naiman and Sibert (1979) reported that scouring of sediments in this estuary had severely limited benthic primary production, but provided no quantitative data to support their view. Other authors have suggested that log storage in the Cowichan, Chemainus, Campbell, Squamish, and Kitimat River estuaries has resulted in some degree of substrate disturbance that has subsequently affected plant communities (Bell and Kallman 1976a, 1976b; E.V.S. Consultants Ltd. and F.L.C. Reed and Associates 1978; Levings and McDaniel 1976).

Plant communities on both rocky and soft substrates may be damaged by log handling. Abrasion-related damage on rock. substrates has been observed at Bath Island, Georgia Strait, where loose logs removed all algal vegetation from flat table rocks but generally not from vertical faces or crevices in the rock (Duval and others 1980). In an attempt to simulate and assess the long-term effects of log abrasion on an algal community, DeWreede (cited in Duval and others 1980) removed Lithothrix sp., a coralline alga, from a portion of intertidal substrate, and found that the area was subsequently recolonized by a filamentous red alga, Rhodomela larix Agardh. In a similar study, Dayton (1971) reported that log abrasion removed intertidal algae from several sites in the San Juan Islands, Washington, and this subsequently affected the species composition of intertidal invertebrate communities.

The potential for plant removal resulting from substrate disturbance depends on the morphology and growth patterns of different algal groups. Perennial plants that can regenerate from the holdfast have a better chance of survival after disturbance than those that require a portion of blade or frond for regeneration. Annuals will not reestablish in a given year if they are removed by substrate compaction or scouring before their reproductive period.

Eelgrass is the most common plant on soft, particularly muddy, substrates in coastal British Columbia waters (Scagel 1971). Several red algae, filamentous greens, and dwarf browns are also adapted to mud substrates in some areas (Ranwell 1972). Abrasion of eelgrass and emergent vascular plants by logs in these soft substrates would likely result in either fragmentation or uprooting of the plants. Although quantitative data are lacking, extensive damage to emergent vegetation fringing intertidal log-storage areas has been noted by several authors. Recovery of eelgrass in areas previously used for log handling was indicated during a study by Pease (1974), and emergent vegetation may similarly recolonize disturbed habitats.

ACCUMULATION OF BARK AND WOOD DEBRIS

Data describing the effects of bark and wood-debris accumulation on plant communities are limited. The effects of log handling on flora of the Campbell River estuary were discussed in a report by E.V.S. Consultants Ltd. and F.L.C. Reed and Associates (1978). Intertidal areas with heavy debris accumulation were characterized by decreased species diversity of benthic flora and oxygen depletion within the sediments, although no adverse impacts of log handling were observed in subtidal regions. Duval and others (1980) summarized several reports that also suggested that bark-debris accumulation may result in decreased abundance of benthic microalgae and macroalgae, but quantitative supportive data are lacking. Pease (1974) examined plant communities (algae and eelgrass) at several abandoned and active log-dumping or storage sites in southeastern Alaska. Plants were sparse at two dump sites that had been in operation for 10 years, but at two other sites in use for only 1 year, green algae (Chlorophyta) and eelgrass were described as "abundant." Pease (1974) found no consistent trends in rates of algal or eelgrass recolonization at log-storage or dumping sites as a function of the period of abandonment.

Accumulation of bark and wood debris could result in direct and indirect, as well as positive or negative, impacts to different types of plant populations, depending on the depth of accumulation and concomitant chemical changes in the environment. The results of studies by Pease (1974) suggest that both microalgae and eelgrass are adversely affected in areas of heavy bark accumulation and poor tidal flushing. On the other hand, scattered and light accumulations of debris could benefit some macroalgae (Kelps) by providing more suitable substrate. Some constituent, such as glucose, in log leachates may also stimulate the growth of plant species capable of heterotrophic uptake. This uptake is not likely to be important with benthic microalgae adapted to low light and relying primarily on heterotrophic production.

CHANGES IN THE LIGHT ENVIRONMENT

Many reports that discussed the impacts of log handling on marine plant communities suggested that shading results from log storage, and increased water turbidity is associated with log dumping and sorting. Although these types of disturbances undoubtedly occur in the light environment, the light intensity, spectral composition, and water turbidity near log-handling sites have not been measured, and adverse effects on plants of these changes have largely been inferred. Similarly, rates of primary production and the standing stock of plant communities affected by various aspects of log handling have not been determined.

The effects of changes in the light environment would probably vary with species and seasonal differences in their light requirements and at present can only be assumed. Greatest impacts would likely occur from shading of plants under rafted logs. Decreased light intensity may reduce rates of primary production and growth, and eventually lead to the loss of benthic microalgae and macrophytes from these areas. On the other hand, free-floating plants (phytoplankton) would not be significantly affected by shading because these organisms would not remain in environments with reduced light.

Particulate matter, such as silt and fine bark debris, may enter the water column as a result of log handling and contribute to increased turbidity. Because no studies have been conducted on turbidity from log handling, we can only assume the effects. When present in sufficient quantities, particulate matter could reduce light intensities and cause changes in the spectral composition of available light because of the tendency for suspended particles to differentially scatter short wavelength (<500 nm) radiation. Both of these changes in the light environment could temporarily affect pelagic or benthic plant communities, either through the effects of light intensity on rates of photosynthesis or by the role of light quality on the differential growth of different species. Impacts of these types are probably extremely localized, however, and of minor concern in log handling in coastal marine environments.

CHEMICAL EFFECTS

To date, the chemical effects of log handling on plant communities have not been examined, although both positive and negative impacts are possible. Chemical changes associated with log handling can include increased BOD and hydrogen sulfide production during the decomposition of wood and bark debris deposits, and the release of log leachates with subsequent physical-chemical effects (increased COD, coloration of water, increased concentrations of dissolved organic compounds). Chemical impacts on plants would probably be restricted to benthic species in the immediate vicinity of heavy accumulations of bark debris and to both pelagic and benthic species near recently watered logs still releasing leachates. Adverse impacts could include sublethal and toxic effects resulting from the presence of log leachates or hydrogen sulfide associated with decomposing bark and wood debris. Decreased autotrophic production, because of the light-attenuating effects of highly colored leachates, could also result. As indicated earlier, log leachates could also have positive influences on plants by increasing the availability of compounds important in the heterotrophic production pathways of some algal species.

SUMMARY OF IMPACTS

Assessment of the impacts of log handling on plant communities is severely limited by lack of quantitative data and the observational nature of existing information. As summarized in table 5, both positive and negative effects on plants could result from physical and chemical factors associated with log dumping, sorting, storage, and transport in

Table S—Sunroary of log-handling Impacts on plant communities

Log-handling effect	Major source of effect	Positive impacts	Mode of action	Negative impacts	Mode of action
Compaction or scouring of soft substrates	Log dumping in shallow areas and Intertidal Tog storage; propeller wash in shallow areas	None		Physical damage and uprooting of eel grass and emergent vegetation; potential decreased primary production by benthic microalgae	Direct
Scouring or abrasion of hard substrates	Log dumping In shallow areas; stranding of lost logs in intertidal environments	None		Physical damage to intertidal algae	Direct
Accumulation of wood and bark debris	Log dumping and sorting; minimal contribution by log storage	Increased habitat for some macrophytes in areas with scattered debris; use of dissolved organic compounds in leachates by heterotrophic forms	Direct and indirect	Decreased species diversity and abundance of benthic microalgae and macrophytes. Potential indirect impacts from chemical changes in bottom waters (H^S and log leachates)	Direct
Changes 1n the light environment (quality and intensity)	Log dumping related to increases in water turbidity; shading by rafted logs; presence of highly colored leachates	Mone		Decreased primary production by autotrophic species; potential changes in species composition in benthic forms under rafted logs	Indirect

	Time considerations					
	Short-term (<10 yr)	Long-term (>10 yr)	Space considerations	Probable recovery potential (years)	Degree of impacts	Factors influencing degree of Impacts
Compaction or scouring of soft substrates	X	None	Insignificant area affected by log dumping; up to moderate coverage of some estuaries	5	Insignificant to minor	Presence of extensive eel grass meadows would increase potential for impacts; intertidal log storage in estuaries would also increase impacts
Scouring or abrasion of hard substrates	X	Hone	Insignificant area of impact 1n regional terms	5	Insignificant	
Accumulation of wood and bark debris	Chemical-related impacts	In areas of heavy debris accumulation and poor tidal flushing	Insignificant to moderate; depending on tidal flushing and log-handling techniques	5-10	Insignificant to moderate	Impact assessment hampered by data deficiencies; impacts would be greatest in estuarine areas where plant communities provide habitat or food for invertebrates, fish, birds
Changes in the light environment (quality and Intensity)	Turbidity and coloration effects	Shading in long-term log-storage areas	Insignificant area of impact	5 5	Insignificant to minor	Shading by extensive log storage in estuaries would increase potential for light-related impacts; also depends on time of year

not applicable

marine waters. Although existing information is not sufficient to define degree of impact accurately, these effects cannot be considered more than minor or moderate in a regional sense. Note that site-specific damage to some plant species, especially eelgrass and emergent vegetation, can be moderate to major. Impacts of log handling on plant communities would be intensified in those coastal areas of British Columbia and southeastern Alaska where emergent vegetation is not abundant, but nevertheless provides important or critical habitat for aquatic birds and mammals associated with shorelines.

Other potential impacts are on estuarine eelgrass and emergent plant communities affected by shading and substrate disturbances that result from storage of logs in shallow waters. A study of log-handling leases in coastal British Columbia waters by FERIC (1980) indicated that 27.2 percent of water leases (2400 ha) were less than 3 m deep, and the potential for damage to nearshore plant communities was highest in these areas. Primary production by benthic microalgae could also be reduced in such areas, and this could subsequently affect secondary production by invertebrate grazers.

DATA DEFICIENCIES

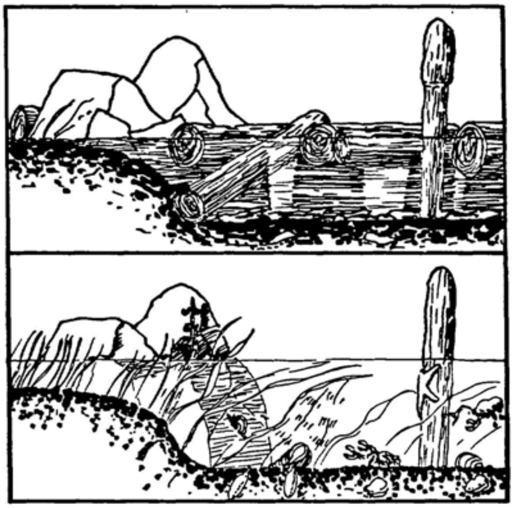
Almost no data are available describing the impacts of log handling on plant communities, with the majority of the available information being either qualitative observations or speculation based on alleged physical-chemical effects. Given the trophic position of plant communities and the fact that production by primary and secondary consumers is closely tied to primary producers, many of these data deficiencies should be subjects of future investigation. Specific areas where information is needed for impact assessment include:

- Quantitative data describing the effects of substrate disturbances on eelgrass and emergent macrophyte beds in estuaries, as well as information documenting rates of recovery after log-handling sites are abandoned, and mechanical bark removal from log-handling sites.

- The effect of bark-debris accumulation on benthic microalgae, including potential sublethal and toxic effects of hydrogen sulfide and log leachates.

- The potential for increased heterotrophic production by plant species affected by certain dissolved organic constituents in log leachates.

- Information describing alteration in the light environment and the effects of potential changes in light quality and intensity on rates of primary production, particularly under rafted logs in estuaries.



IMPACTS OF LOG HANDLING ON BENTHIC AND INTERTIDAL INVERTEBRATES

The effects of log handling on benthic invertebrates in coastal environments have been described in qualitative studies at log-dumping and storage sites in southeastern Alaska and Howe Sound, British Columbia (Ellis 1973, McDaniel 1973). Quantitative studies that examined the abundance and diversity of benthic organisms relative to log handling have also been conducted in southeastern Alaska (Pease 1974), British Columbia (Conlan 1977, Conlan and Ellis 1979, Sibert and Harpham 1979), and Washington and Oregon (Schaumburg 1973, Smith 1977, Zegers 1978); reviews of available literature describing impacts of log handling on invertebrates were provided by Conlan (1975, 1977), Hansen and others (1971), and Smith (1977).

These studies suggest that the effects of log handling range from major changes in the physical environment—which results in decreased abundance of benthic invertebrates, changes in community structure, or both—to localized positive influences on some invertebrates associated with bark and debris habitat. These studies also indicate that log-handling effects on benthic and intertidal invertebrates are related to: direct physical disturbances to the sea bottom (scouring, filling, and compaction of the sediment) at log dumps and intertidal storage sites; the accumulation of bark and other debris from dumping, sorting, and storage activities; or both. The spatial extent and degree of impact are directly related to the flushing characteristics of waters near the log-handling site, the methods of handling logs, the intensity of use in each area, the location of these areas, and the ecological and commercial importance of affected species.

IMPACTS OF PHYSICAL DISTURBANCE

At log-dump sites, impacts associated strictly with scouring and compaction of the bottom sediments have not been documented. This is largely because at shallow-water dump sites, where bottom disturbance is likely (such as dumps using parbuckle, slide-ramp systems, or both), large amounts of bark and wood debris frequently accumulate, so separating the effects of these two forms of disturbance is difficult. Fauna are expected to be depleted in the relatively small areas where logs come in contact with the bottom during dumping. Fauna that could be affected include clams, crabs, oysters, sedentary polychaetes, and any other animals that depend on macroscopic plants--such as eelgrass—that may be eliminated during dumping activities in shallow water. Because the areas directly affected by physical contact with logs at dump sites are usually small relative to the available habitat in adjacent areas (about 200 ha in coastal British Columbia, FERIC 1980), the total effect of physical substrate disturbances at dump sites to coastal benthic invertibrate communities is minor.

Physical disturbance to the substrates at log-storage sites has only been documented in intertidal storage areas where log booms or bundles "ground" during low tide. In these areas, changes in abundance of invertebrates, species composition of invertebrate communities, or both have been significant and measurable. Repeated grounding of log booms during low tides causes sediment compaction which either prevents substrate use by macro-infaunal species (predominantly suspension feeders, such as clams) and results in a shift to predominantly infaunal detritus feeders or occasional elimination of the benthic infauna by crushing (Pease 1974, Sibert and Harpham 1979, Smith 1977, Zegers 1978). For example, at Buckley Bay on Vancouver Island, Conlan and Ellis (1979) reported that populations of clams and oysters were reduced in areas of intertidal log storage as a result of sediment compaction. Studies in southeastern Alaska by Pease (1974) and in Washington by Smith (1977) also indicate significant decreases in the abundance of benthic epifauna and infauna at intertidal storage sites where sediment compaction had occurred over prolonged periods. Zegers (1978) found the total number of benthic organisms on grounded areas of Coos Bay, Oregon, to have been reduced between 88 and 95 percent. Direct physical disturbance to benthic infauna and plants providing habitat for epibenthic organisms may also result from the propeller wash of log dozers and tugs operating in shallow waters. Impacts of this type have included windrowing of oysters and washout of clams (Duval and others 1980).

On the other hand, Sibert and Harpham (1979) observed no adverse effects of intertidal storage on benthic epifauna in the Nanaimo River estuary. They found a greater density of epibenthic harpacticoid copepods (an important prey species of some species of juvenile salmon) under intertidal log booms, but reported no consistent trends in harpacticoid densities relative to the intertidal storage of flat rafts or bundles. Although measurements of infaunal abundance were not undertaken during this study, Sibert and Harpham (1979) did suggest that infaunal habitat was probably reduced by sediment compaction.

Levy and others (1982) used basket traps and stream samples to compare the relative abundance of epibenthic invertebrates in the Point Grey log-storage area and the Musqueam Marsh in the north arm of the Fraser River estuary. They found the mysid *Neomysis mercedis* Holmes was more abundant in the log-storage area, the isopod *Gnorimosphaeroma oregonensis* Dana was more abundant in the marsh, and the amphipods *Eogammarus confervicolus* Birstein and *Corophium* sp. were similar in abundance in the two areas. They conducted three large-scale invertebrate-distribution studies and found that in two of the studies E. *confervicolus* was uniformly distributed throughout the two study areas. *Corophium* sp. were most numerous along the marsh-log storage boundary, and relatively high numbers of G. *oregonensis* were found throughout the Musqueam Marsh. Levy and others (1982) believe that the hard-sediment consistency in the log-storage area caused by repeated log groundings may have reduced the abundance of *Corophium* sp. They also believe the low salinity of the Musqueam Marsh and the intermediate salinity of the Point Grey log-storage area may have caused mortality of *Corophium* sp. and *E. confervicolus*, respectively.

Another source of physical disturbance to intertidal invertebrates is the accumulation of lost logs along shorelines. Data describing the effects of this disturbance to intertidal fauna are limited (Dayton 1971), although both positive and negative influences are lik-ely. In rocky areas, stranded logs may crush organisms, particularly those logs that are repeatedly moved to different areas on subsequent tidal cycles. On gradually sloping shorelines where most log accumulation occurs (Waeiti and MacLeod 1971), substrate compaction may affect infauna in the same way as log grounding affects it in intertidal storage areas. On the other hand, some intertidal organisms may benefit from log-debris accumulation in the intertidal zone. For example, the amphipod *Anisogammarus confervicolus* Stimpson and the isopod *Exosphaeroma oregonensis* Dana are extremely abundant within and adjacent to decomposing logs and wood debris in the mud flats of the Squamish River estuary (Levings and McDaniel 1976), although deeper areas in the substrate characterized by high concentrations of hydrogen sulfide are devoid of macrofauna (Duval and others 1980). Increased habitat associated with log debris is likely to be most beneficial to those organisms inhabiting the upper portions of the intertidal zone characterized by "old drift" (Waeiti and MacLeod 1971).

IMPACTS OF BARK AND DEBRIS ACCUMULATION

Most of the impacts of log handling on benthic and intertidal invertebrates have been attributed to the accumulation of bark and other debris at log-transfer and storage areas. Although the direct effects of substrate disturbance at these sites are relatively localized, bark and wood debris can spread beyond the immediate area of log dumping, sorting, or storage operations (Conlan 1977). Measured spatial extents of debris accumulation have ranged from only scattered deposits below subtidal log-storage sites (Ellis 1973, Pease 1974) to about 1 ha (Schultz and Berg 1976) to continuous debris accumulations covering areas up to 1 km^2 around active and abandoned dump sites (Conlan 1977).

The documented impacts of debris and bark deposits on benthic invertebrates are related to chemical changes in the environment (depletion of oxygen, toxic levels of hydrogen sulfide, and wood leachates), and to physical changes in sediment composition (increased amounts of wood and bark on top of and within the sediments). The extent of these physical changes depends on the amount of tidal flushing in the log-handling area; the methods used to dump, sort, and store logs; and the length of time the area has been used for log handling.

CHEMICAL EFFECTS

Some authors have suggested that the chemical effects associated with bark- and wood-debris accumulations have a minor impact on benthic organisms. Studies by Pease (1974) and Schaumburg (1973) indicate that the BOD of these materials is low enough that oxygen levels in waters within or above the substrate are generally unaffected or at least not significantly changed from those normally associated with marine sediments. Similarly, the opportunity for dilution available in most log-handling areas usually prevents accumulation of hydrogen sulfide or wood leachates in the water column. Exceptions have been documented in poorly flushed areas where extensive debris has accumulated on the substrate. For example. Pease (1974) found one log-dumping site in southeastern Alaska where low oxygen and high hydrogen sulfide concentrations and wood leachates were associated with a virtual absence of benthic fauna. Ellis (1973) also reported that epibenthic organisms were less abundant in log-handling areas where thick layers of decomposing bark and wood debris were deposited. The latter study, however, was based only on divers' observations; as a result, the effects of low oxygen and high hydrogen sulfide concentrations could not be distinguished from the concurrent physical changes in sediment composition. Because a relatively large proportion (4208 ha or 47 percent) of the British Columbia log-handling lease areas in water that were examined by FERIC (1980) were located in areas with negligible tidal currents, the potential for chemical impacts to benthic invertebrate communities may exist at several coastal British Columbia log-handling sites.

Conlan (1975) stated that quantitative information was lacking on the accumulation of leachates or hydrogen sulfide in interstitial or intertidal environments near log-handling sites. Both of these environments are directly affected by the decomposition of bark and wood deposits, and some may have limited flushing potential. Although hydrogen sulfide is toxic to some fish (McKee and Wolf 1963), marine benthic infauna are normally exposed to hydrogen sulfide produced by decomposition in the sediments and are unlikely to be greatly affected by the additional hydrogen sulfide associated with decomposition of bark. and wood debris. On the other hand, some epifauna and pelagic invertebrates (for example, zooplankton) could be adversely affected by hydrogen sulfide accumulating in the water column of poorly flushed areas. No data are available on the toxicity of hydrogen sulfide to epibenthic and pelagic marine invertebrates.

The potential toxicity of log leachates to marine fauna is negligible because of the tendency for lignin constituents to precipitate with divalent cations **in** seawater (Schaumburg 1973). Nevertheless, accumulation of leachates in freshwater or slightly brackish log-handling areas--such as the tidal portion of rivers--still represents an area of possible impact, primarily because of the effects of plicatic acid on the pH of these poorly buffered waters (Peters 1974). The toxicity of log leachates to marine and freshwater invertebrates has been examined in laboratory bioassays by Buchanan and others (1976) and Peters and others (1976), respectively. Peters and others (1976) reported that the 96-h LC50 (concentration required to produce 50-percent mortality of test organisms within a specified time) of western redcedar leachates to mayfly nymphs (*Ephemerella inermis* Eaton) was 4.4 mg/liter. The lower toxicity of log leachates in marine environments is substantiated by the studies of Buchanan and others (1976), who examined the effects of spruce and hemlock leachates on larval and adult pink shrimp (*Pandalus borealis* Kroyer) and larval Dungeness crab (*Cancer magister* Dana). The 96-h LC^Q of spruce extracts to larval shrimp, adult shrimp, and larval crabs was 415, 205, and 530 mg/liter, respectively; the hemlock extracts were only slightly toxic (96-h LC^Q was 1000 mg/liter) to adult shrimp and nontoxic to both shrimp and crab juveniles. By comparison, the highest leachate concentrations observed in nature (280 to 320 mg/liter) were those measured by Pease (1974) in a poorly flushed, Alaskan log-storage site. These concentrations were about five times the threshold concentrations for acute toxicity determined by the same author in laboratory bioassays with pink salmon fry, but bioassays were not conducted at the storage site to determine if these receiving waters were actually toxic to benthic fauna.

In summary, the potential chemical effects of debris accumulation to benthic and intertidal fauna remain poorly defined. In most log-handling areas, significant impacts **are** unlikely, although several relatively serious data deficiencies do exist. Of particular concern is the lack of data describing potential effects of hydrogen sulfide and leachates (sublethal and lethal) in log-handling sites with negligible tidal flushing, which according to the recent survey of FERIC (1980) account for about 47 percent by area of log-handling sites in British Columbia.

PHYSICAL EFFECTS

The most thorough examination of the physical effects of bark and debris accumulation on benthic infaunal organisms was made by Conlan (1977) at Mill Bay, British Columbia. In this study, the physical effects of debris were clearly separated from the concurrent effects of chemical changes in the environment. The sand-bottom habitat in control areas with no debris accumulation was characterized by a wide diversity of organisms, including suspension-feeding bivalves and polychaetes. In areas with debris accumulation, the benthic community was altered in the following ways:

- Suspension-feeding organisms were eliminated.
- Dominant species were fewer and invertebrate biomass was less than in control areas.
- Numbers of wood-boring bivalves (*Bankia* sp.) and isopods (*Limnoria* sp.) were greater than in control areas.

Conian (1977) also found that these effects were particularly evident where depth of debris exceeded 1 cm. Areas that had been abandoned for 17 years or more showed little recovery in normal community structure and abundance. Her results were generally consistent with those of earlier investigations of benthic infauna at active and abandoned log-handling areas (Conian and Ellis 1979, Pease 1974) and demonstrated that, although the changes to infauna are not necessarily pronounced, they are measurable.

In general, the accumulation of bark and debris has had little adverse effect on epibenthic commmunities. In areas with thick, soft deposits of decomposing bark but no sunken logs, Ellis (1973) reported fewer epibenthic species (such as crabs) and attached forms (including anemones and tunicates). At sites where scattered bark and sunken log debris provided additional habitat, however, Conian and Ellis (1979), Ellis (1973), McDaniel (1973), and Pease (1974) all reported increased abundance of epibenthic fauna, particularly amphipods, *Munida* sp., shrimp, crabs, anemones, and tunicates. In sunken logs and accumulations of wood debris, wood-boring bivalves and isopods were numerous. Although the increased habitat for wood-boring organisms would be considered a positive impact of log handling biologically, it is a negative impact of log-handling operations.

The evidence to date therefore suggests that the infaunal suspension-feeding organisms (living within the sediment) are adversely affected by the physical changes associated with accumulation of bark and wood debris, while the epibenthic organisms remain generally unaffected or sometimes may benefit from increased habitat. The only situation where adverse impacts to epifauna have been indicated is where decomposition of bark debris results in a soft, flocculent substrate (Conian 1977).

SUMMARY OF IMPACTS

A summary of various physical and chemical effects associated with log handling on benthic and intertidal invertebrates is provided in table 6. For some categories of effects, such as those related to chemical changes in benthic habitats, limited information is available on which to base assessments, while other types of effects are better documented. For each type of disturbance indicated in table 6, degree is largely determined by the spatial extent of the log-handling operation; its location with respect to potentially sensitive areas, such as estuaries; and the ecological, commercial, or recreational importance of affected resources. On a regional basis, impacts on benthos associated with accumulation of bark and wood debris are rated as minor to moderate as a result of apparent slow recovery of the substrate of many areas that have been inundated with debris, although site-specific impacts to benthic invertebrates can be moderate to major.

In conclusion, the most significant negative impacts of log handling are destruction of habitat and crushing of benthic organisms in intertidal log-storage sites, and alteration of benthic infauna habitat and abundance as a result of wood-debris and bark accumulations from dumping and water sorting, and, to a lesser extent, from log storage. Both of these forms of impact have been documented from log-handling sites on the west coast, and have sometimes been responsible for local reductions in commercially important bivalve populations (clams and oysters), reductions in fish-food organisms (suspension-feeding polychaetes), and increases in wood-boring forms.

Table 6--Summary of log-handling impacts on benthic and intertidal invertebrates

Log-handling effect	Major source of effect	Positive impacts	Mode of action	Negative impacts	Mode of action
Bottom scouring	Free-fall dumping in shallow waters (including barge dumping); tug wash in shallow estuaries			Crushing of epifaunal and infaunal species; habitat disturbance	Direct
Sediment compaction	Free-fall dumping in shallow waters and intertidal log storage	Possible increase in abundance of some species of mobile epifauna such as harpacticoids	Indirect	Destruction of habitat and crushing of suspension-feeding fauna (bivalves, polychaetes); decrease of infauna and sedentary species of epifauna	Indirect; direct
Bark and debris accumulations: lowered oxygen levels; toxic accumulations of H_2S and log leachates	Free-fall dumping; water sorting; log storage is generally a minor contributor	None	—	Mortality of epifauna and infauna; potential sublethal effects resulting in altered secondary production	Direct
Physical changes in sediment and bottom composition	Free-fall dumping and water sorting; flat-rafting may contribute to log sinkers	Increased abundance of epifauna where scattered bark and debris provide additional habitat and attachment sites (wood-boring species, amphipods, shrimp, prawns, crabs, tunicates, nonburrowing anemones)	Indirect	Infauna—decreased biomass, elimination of suspension-feeders (bivalves and polychaetes); lower species diversity Epifauna—reduced abundance when bark and debris have decomposed to soft, flocculent consistency	Indirect

	Time considerations					
	Short-term (<10 yr)	Long-term (>10 yr)	Space considerations	Probable recovery potential (years)	Degree of impacts	Factors influencing degree of impacts
Bottom scouring	X	None	Insignificant area of impact in relation to available habitat	<5	Insignificant to minor	Dumping or other activities causing scouring in important areas, such as estuaries or commercial/recreational shellfish-harvesting areas, would lead to minor impact
Sediment compaction	X	If site used continuously	Insignificant area for dumping; insignificant to moderate area for rafting-storage areas	<5	Insignificant to moderate (moderate when site used 10 years)	Large storage areas in important estuaries or commercial/recreational shellfish-harvesting areas; duration of use of log-handling area
Bark and debris accumulations: lowered oxygen levels; toxic accumulations of H_2S and log leachates	X	None	Insignificant to moderate depending on tidal flushing and log-handling techniques	<5 (depending on rate of decomposition)	Insignificant to moderate	Few reported instances; lack of information for benthic environments; dumping and sorting in important estuaries or commercial/recreational shellfish areas may increase impacts
Physical changes in sediment and bottom composition	None	X	Minor to moderate, depending on tidal flushing and log-handling techniques	<5	Minor to moderate	Extent of debris coverage; importance of area; important estuary or commercial/recreational shellfish-harvesting area

not applicable

Some benthic invertebrates benefit from log-handling activities. These are primarily epibenthic species, which increase in abundance in log-storage areas characterized by scattered deposits of Dark and wood debris. These species include wood-boring bivalves and isopods, nonburrowing sea anemones, barnacles, tunicates, amphipods, Mundia sp. (in deeper waters), shrimp, and harpacticoid copepods. Some of these invertebrates are important fish-food organisms (amphipods and copepods) or potential commercial species (shrimp, prawns, and crabs).

DATA DEFICIENCIES

Major data deficiencies that have limited assessment of the impacts of various aspects .of log handling on benthic and intertidal invertebrates include:

- Information related to the concentration of hydrogen sulfide and log leachates in poorly flushed interstitial and pelagic habitats, and the potential toxic and sublethal effects of these chemicals on benthic infauna, epifauna, and pelagic invertebrates.

- Data describing potential sublethal effects of physical and chemical changes resulting from accumulation of bark and wood debris, particularly information describing the bioenergetic effects of log handling on estuanne and intertidal benthic invertebrate communities.

- Quantitative data describing the relative effects of intertidal flat-raft and bundle-boom storage on the degree of sediment compaction, redox potential, and subsequent impacts to benthic infauna.

- Information describing the effects of log storage (both intertidal and subtidal) on the community structure and abundance of sedentary and mobile epifauna.

IMPACTS OF LOG HANDLING ON FISH

Fish species that may inhabit the areas most frequently used for log handling (estuaries, sheltered bays, and inlets) include the anadromous salmonid species (salmon, cutthroat and rainbow trout, Dolly Varden), marine smelts (surf smelts, capelin, longfin smelt, eulachon), herring, various rockfish, and bottom-dwelling fish species. In addition to the commercial and recreational importance of some of these species, many also represent important prey species for marine mammals and aquatic birds. The life-history phases of these fishes that are most likely to be affected by log handling include rearing (all species), migration (salmonids, smelts), and spawning and incubation (smelts, herring). The timing of the life-history phases for important fish species found in Pacific Nortnwest coastal waters is presented in table 7.

The direct impacts of log handling on fish have not been quantitatively assessed except by Levy and others (1982). The following sections therefore describe probable effects of log handling, based on observations of other communities, such as benthic invertebrates, and on indirect evidence of impacts cited in Cue few references available on this topic.

Table 7—Life-history phases of some important fish in British Columbia coastal waters

Fish	Activity	Month											
		J	F	M	A	M	J	J	A	S	O	N	D
Salmomds	Fry/smolt estuary1/ residence	-	-	-	-	-	-	-	-	-	-	-	-
	Adult migration staging	-	-	-	-	-	-	-	-	-	-	-	-
Herring	Spawning activity		-	-	-	-	-	-	-				
	Rearing activity			-	-	-	-	-	-	-			
Surf smelt	Spawning and incubation	-	-	-	-	-	-	-	-	-	-	-	-
	Residence	-	-	-	-	-	-	-	-	-	-	-	-
Capelin	Spawning and incubation									-	-	-	
Longfin smelt	Adult migration										-	-	-
	Residence	-	-	-	-	-	-	-	-	-	-	-	-
Eulachon	Adult migration and recovery		-	-	-	-	-						

1/ Information on timing from Hart (1973),

DIRECT IMPACTS

The most comprehensive study of fish densities, growth, and feeding behavior was conducted in the Fraser River estuary (Levy and Others-1982). Within the north arm of the estuary, a pristine marsh was compared with a marsh with extensive log-storage booms. Levy and others (1982) found salmonid fish densities to be similar in both areas. They concluded juvenile salmon did not avoid stored-log booms in this well-flushed estuary. They also found chinook salmon fry in the log-storage area to be significantly larger than in the pristine marsh site (one-way ANOVA results: $F_{2,240} = 6.03$, $p < 0.01$) Their data,cate that growth conditions may be relatively good for chinook fry in the log-storage area. They found no size or growth-potential differences between log-storage areas and the pristine marsh for chum salmon fry.

Juvenile salmon in two adjacent intertidal areas of the Fraser estuary, the Point Grey log-storage area, and the Musqueam Marsh displayed major dietary differences (Levy and others 1982). This dietary shift in the log-storage area appeared to be caused by a decrease in estuarine insects because marsh plants were absent there and the mysid <u>Neomysis mercedis</u> and fish larvae were more available.

Levy and others (1982, p. 66) concluded Chat "in spite of the drastic physical impact of intertidal log storage at Point Grey there was no strong negative effect on fish utilization of the area. There were no decreases in fish abundance, or fish growth Chat could be attributed to the presence of stored log booms." Because the Point Grey log-storage area is well flushed, they suggest research is needed to test the hypothesis Chat fish also do not avoid log booms in poorly flushed log-storage areas.

Potential direct effects of log handling on fish may result from physical disturbances associated with log-transfer and sorting activities. Physical effects, such as bark accumulation, may suffocate incubating eggs or interfere with fish habitat use. Direct impacts may also result from the chemical effects of log leachates released from stored logs and the oxygen demand of decomposing wood and bark debris at log dumps and, to a lesser extent, log-storage sites. No information on the importance of these direct disturbances to fish populations is available, however.

Large numbers of salmon occur in many rivers, estuaries, and coastal areas during the periods of juvenile rearing, as well as during adult spawning migrations to natal streams (Levy and others 1979, Neave 1966, Scott and Crossman 1973, Stasko and others 1973), while anadromous cutthroat trout. Dolly Varden, and steelhead trout may use some of these coastal environments throughout the year (Scott and Crossman 1973). Other species, including smelt and herring, may concentrate in estuaries, inlets, and bays during their spawning and migration periods (table 7). Only the surf smelt, capelin, and herring spawn and deposit eggs in marine environments potentially used for log handling, however (Hart 1973). Quantitative assessment of impacts is impossible because direct effects of log handling on fish have not been studied. Log-transfer and sorting activities, however, are unlikely to interfere significantly and directly with fish outside the relatively small area where the disturbances occur, and fish would probably avoid such areas. Nevertheless, log dumping, tugboat wash during sorting, and intertidal log storage may destroy some of the incubating eggs of smelt and herring. Other fish, including shallow-water rockfish and bottom-dwelling species, are widely distributed in coastal British Columbia, southeastern Alaska, and Puget Sound waters. The areas used for log handling represent only a minor portion of their available habitat. Note, however. that no data are available to describe the site-specific impacts of log handling on the limited, unique habitats for some fish resources and the potential for disproportionate effects of these activities on fisheries productivity.

The potential chemical effects of log leachates on fish have been examined in several laboratory bioassays and in limited field studies, including those of Pease (1974) and Schaumburg (1973). In laboratory experiments, log leachates have been shown to be toxic to fish and also to contribute to increased chemical oxygen demand in the water. The toxicity of leachates is significantly lower in sea water and in marine environments with low salinity (<20 parts per thousand) than in fresh water, however. Both Pease (1974) and Schaumburg (1973) concluded that the large volume of water available for dilution usually prevents either accumulation of leachates to toxic concentrations or reduction in oxygen concentration that could adversely affect fish. Any increase in leachate concentration that could be toxic would usually be temporary and extremely localized. Of 13 active or inactive dumping and storage areas examined by Pease (1974) in southeastern Alaska, only one site (with limited tidal flushing and heavy debris accumulation) had leachate and oxygen concentrations that could adversely affect fish. No information is available, however, on the frequency of this type of occurrence in British Columbia. The relatively high proportion (47 percent) of coastal British Columbia log-handling sites reported to have negligible tidal flushing (FERIC 1980) suggests that direct chemical impacts of this type may occur in some areas.

INDIRECT IMPACTS

Alterations in fish habitat or in the abundance of fish-food organisms may indirectly affect fish populations either positively or negatively. For example, FERIC (1980) reported that many coastal log-handling sites in British Columbia are located in intertidal or estuarine areas (3374 ha; 37 percent). Many of these areas support communities of eelgrass, rockweed, or both--which are common substrate for deposition of herring spawn (Outram and Humphreys 1974, Patterson 1975). Several authors suggest that the abundance of aquatic flora has been significantly reduced in some intertidal areas used for log storage (for example, Ladysmith Harbour, Nanaimo and Squamish River estuaries) through shading (Ministry of Environment, British Columbia 1976; Waldichuk 1979), grounding of rafts with resultant scouring and compaction of sediments (Pease 1974, Sibert and Harpham 1979, Waldichuk 1979), and uprooting of plants resulting from tugboat activity (Sibert 1978). These impacts may be responsible for elimination of herring-spawn deposition in Ladysmith Harbour near Dunsmuir Island (Patterson 1975) and in the Mamquam Channel area of the Squamish River estuary (Hoos and Void 1975). No evidence suggests, however, that herring losses have resulted. Healey (1978) suggested that intertidal log storage has resulted in the destruction of some juvenile salmon rearing-habitat in the central and western portions of the Nanaimo River estuary, although quantitative data to substantiate his hypothesis are apparently lacking.

The abundance of benthic epifauna and infauna, which may be important fish food, is also reported to be decreased in some areas where bark and wood debris accumulate or where intertidal log storage occurs (Conlan 1977, Ellis 1973, Pease 1974). As a result, fish populations using these nearshore environments may be indirectly affected. At the same time, despite reductions in some invertebrate species, several fish-food organisms often appear to be more abundant in some areas where scattered log-debris and bark deposits occur. For example, Levings (1973) noted large populations of amphipods (*Anisogammarus pugettensis* Dana) in association with a dense diatom-chlorophyte community among older logs stored in the Squamish River estuary. Goodman and Vroom (1972) reported that salmonids using this area preyed on these amphipods. Similar indirect positive impacts of log handling have been recorded in the Kitimat River estuary (Higgins and Schouwenberg 1976, Paish and Assoc., Ltd. 1974); Conlan (1977) also reported that the abundance of amphipod species is either increased or unaffected by log storage.

Although some authors have inferred that compaction of sediments under intertidal log booms has contributed to a decrease in benthic amphipods and copepods that serve as major food items for juvenile salmon (Healey 1978, Waldichuk 1979), this relation has not been satisfactorily demonstrated. Sibert (1978) and Sibert and Harpham (1979) reported that, although larger infauna were removed from log-storage areas of the Nanaimo River estuary, the total abundance of major meiofauna taxa, nematodes, and harpacticoid copepods (important prey items of juvenile chum salmon) could not be related to the presence of log booms.

Some observations also suggest that some fish species, including prey species of marine mammals, may be attracted to areas where logs are stored or where wood and bark debris increases the abundance of food sources. In areas of undecayed bark and debris accumulation, Ellis (1973) found sandlance, species of blennies and cottids, as well as yellowfin sole, using habitat under log-storage areas in Hanus Bay, Alaska. Schultz and Berg (1976) also reported fish species--such as cod, shiner, perch, and searcher--in association with submerged logs, branches, and benthic bark deposits in southeastern Alaska.

Apparently, therefore, the allegations that log dumping, sorting, and storage have contributed to reduction in fish habitat and fish-food organisms are based on circumstantial evidence.

One frustrating aspect of our concern for the environment is the lack of research data to support decisions. With the exception of the Nanaimo River estuary on southeastern Vancouver Island, no comprehensive ecological study of log-rafting and storage impacts on the total estuary has been made. Intertidal habitats have been well documented near mill sites in Oregon, Washington, and British Columbia. Leachate toxicity and BOD problems, although well documented in

the laboratory, have not been documented in the field. Environmental concerns related to log transportation in southeastern Alaska are poorly based in fact; a well-organized study of the estuarine ecosystem should be conducted on both benthic and epibenthic organisms.

SUMMARY OF SIGNIFICANT IMPACTS

Assessment of log-handling impacts on fish is limited by the lack of direct quantitative information. Most of the alleged negative impacts of log handling on fish are speculative, based on few observations and no quantitative studies. A summary of potential direct and indirect impacts of log handling on fish is provided in table 8. The degree of potential negative impact to coastal British Columbia and southeastern Alaska fish resources probably ranges from insignificant to minor. The greatest potential for negative impacts is from the destruction of herring spawning areas. Other negative impacts are probably relatively localized and not likely to have serious effects on fish. Some observations also suggest that positive indirect impacts to fish may result from increased abundance of invertebrate food organisms in some areas of log storage and log-debris accumulation.

DATA DEFICIENCIES

The following data deficiencies have severely hampered delineating the impacts of log handling on coastal British Columbia fishery resources:

- Few studies have addressed the direct or indirect effects of dumping and log sorting on fish in log-handling areas, particularly on rearing juvenile salmonids or migratory adults.
- No adequate study has been conducted of the impact of the loss of eelgrass beds on herring populations in log-storage areas.
- Studies have not been conducted on sublethal effects of log leachates on fish'in their natural habitat.
- Information is lacking on concentrations of leachates or leachate-derived chemicals in British Columbia log-handling areas.

Table S—Suimiary of log-handling Impacts on fish

Log-handling effect	Major source of effect	Positive Impacts	Mode of action	Negative impacts	Mode of action
Physical disturbance to water column and bottom	Free-fall dumping; water sorting in shallows; Intertidal log storage	None		Disturbance to fish present; destruction of herring and smelt spawn	Direct
Accumulation of bark and log debris and floating materials	Log storage and bark- and wood-debris accumulations at dump and water-sorting areas	Increased abundance of some fish-food organisms; possible attraction of some species to log-raft or debris habitats	Indirect	Toxicity or sublethal effects from log leachates and low dissolved oxygen	Direct
				Loss of fish-food organisms in areas of heavy debris accumulation	Indirect
Bottom compaction and scouring	Free-fall dumping; water sorting; intertidal log storage	None		Loss of aquatic plants for herring spawning; loss of invertebrate food organisms	Indirect

Log-handling effect	Time considerations: Short-term (<10 yr)	Time considerations: Long-term (>10 yr)	Space considerations	Probable recovery potential (years)	Degree of impacts	Factors affecting degree of impacts
Pnysteal disturbance to water column and bottom	x	None	Localized; areas of fish use are site- and time-specific	<5	Insignificant to minor	Fish use depends on time of year and is restricted to some areas (no documented .evidence of impact)
Accumulation of bark and log debris and floating materials	X	None	Localized and depends on the degree of available dilution	<5	Insignificant	Toxicity-related Impacts *may* increase with decrease in salinity and decrease in degree of tidal flushing (no documented instance of toxicity to fish in field)
			Restricted to areas of debris accumulation	>5	Insignificant to minor	Advanced decay of bottom debris will reduce Invertebrate food sources
Bottom compaction and scouring		None	Restricted mainly to areas of direct bottom disturbance	>5	Insignificant to moderate (potential)	Importance of spawning area and aerial extent of disturbance determine site-specific impact (no documentation of effects to fish populations)

not applicable

INTENSITY OF LOG RAFTING AND FOREST OPERATIONS: REGIONAL DIFFERENCES

The history of development of the timber industry in western North America reflects geographical patterns. The shipping and cargo mills described earlier led to the development and persistence of processing centers located to accommodate both railways and seaports. The interiors of British Columbia, Washington, Oregon, Idaho, Montana, and northern California developed with the railroads and the mining industry. The problems and phasing of log handling in fresh water are different from those in salt water.

The freshwater problems are largely historical. Although the extent and pervasive impact on western rivers is impressive, physical alterations do not exist entirely as a result of log handling. They persist because of log-salvage policies for road and bridge protection, flood reduction, and debris control, and because of current fish-habitat management guidelines.

Degradation of water quality has eased considerably because of new laws and better enforcement. Economic factors have played a large part by the continual closing and consolidation of wood-processing facilities. McHugh and others (1964) reported that about 4860 ha of log ponds and 800 ha of sloughs or canals used as log-storage sites existed in Oregon; in Washington, about 1620 ha of log ponds and 600 ha of sloughs were used for log storage; northern California had about 1620 ha and Idaho had 400 ha. The size of the ponds varied from less than 1 ha to over 160 ha in surface area and from 1 m to 9 m in depth. These figures are probably half as large now, because of mill closures and dry-land sorting and processing.

Lumber production in the western United States is illustrated in figure 4. The use of water for log storage and transportation in the West reflects the same trends that were seen in Washington during its peak transfer production in the late 1920's. Oregon did not reach a peak until the late 1950's and early 1960's. Large-scale timber production did not begin in Alaska until pulp mills were built at Ketchikan and Sitka in the mid-1950's and early 1960's. Timber production in southeastern Alaska reached a peak in the early 1970's. British Columbia reached a peak at the end of the 1970's. With improvement in the world economy, this upward trend should continue. The greatest use of water for transportation in Idaho and Montana occurred between 1906 and 1929 with mills located on the shores of the large lakes (Pend Oreille, Coeur d'Alene, and Flathead). These lakes experienced significant log traffic during this period. California's timber production peaked in the mid-1920's and again in the mid-1950's. Along the coast of California, river transportation of logs declined Co the point where it no longer seriously affected fish habitat by 1890, particularly in Cue Monterey Bay area and in Mendocino County, north of San Francisco Bay; log storage similarly declined by 1920.

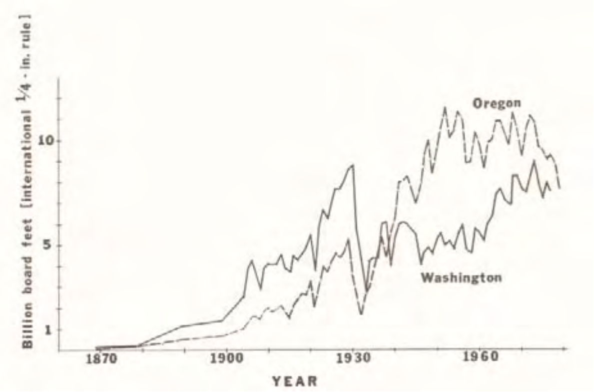


Figure 4.—Lumber production in Oregon and Washington, 1869-1980.

HISTORICAL INTENSITY OF LOG RAFTING IN WESTERN NORTH AMERICA

OREGON

Oregon's major rivers, the Columbia and Willamette, have been used intensively from the beginning of timber production to the present for log Handling and transportation. Its estuaries were also used intensively. For perspective, Oregon's estuaries are shown in table 9, starting at the northern border and moving to the south, along with surface areas, percent tidelands, and size of drainage basins. Estuary surface areas are from work by Johnson (1972), Marriage (1958), Oregon Division of State Lands (1973), and Percy and others (1974). Marriage did

Table 9—Surface areas, percent tidelands, and drainage areas of Oregon's estuaries (from Percy and others 1974)

Estuary	Surface area measured at			Surface area in tidelands		Drainage basin area
	High water	Mean high tide	Other			
	- - - - - - - Hectares	- - - - - - - -		Percent		km^2
Youngs Bay			1/1 162.4			312.8
Necanicum		·	2/112.6			233.1
Nehalem	967.1	935.2	2/1 525.2	32	47	2 192.3
Tillamook	3 588.7	3 357.1	3/3,579.8	58	50	1 384.6
Netarts	88.5	941.6	3/974.4		65	35.9
Sand Lake	178.8	213.8	1/283.5	—	75	43.6
Nestucca	413.9	405.0	465.4		85	825.6
Salmon River	69.3	82.6	1/177.4	57	62	192.3
Siletz	439.8	480.7	487.2		65	956.4
Yaquina	1 714.4	1 583.6	1/1 162.4	61	35	648.7
Alsea	866.7	869.1	l/gog.g		46	1 215.4
Siuslaw	590.5	909.2	643.6	38	34	1 982.1
Umpqua	2 733.4	2 766.2	2 313.4	27	22	11 692.3
Coos	4 444.1	••	3 864.9	48	--	1 551.3
Coquil1e	331.3	--	1./284.7	--	--	2 712.8
Sixes			133.7			330.8
Elk	-		1/117.5	--	--	241.0
Rogue	232.9	-	-•	•	--	13 076.9
Pistol			i/93.2	•	-	271.8
Chetco	56.7				—	920.5
Minchuck	—	--	i/52^7	--	""	179.5

— = no data available.

I/ Area calculated by planimeter; shoreline representing approximate line of mean high water.

V Tidal stage not given; described as "the estuary covers 278 acres."

3/ Tidal stage not given; described as "those areas affected by tidal action."

4/ Area calculated by planimeter from aerial photographs; tidal stage not known.

not specify the relation of the tidal stage to the areas, but tie did state that "only chose areas affected by tidal actions were included in the acreage measurements." He determined the areas sometime around 1948 from either U.S. Coast and Geodetic Survey (USCGS) bay charts (preferably) or coastal charts, but made no indication as to which type was used for the individual estuaries. He also usually recorded tne number of tideland acres. Johnson apparently used USCGS charts from the late 1960's and early 1970's to determine surface areas. The Oregon Division of State Lands (1973) obtained mean low tide and mean high tide surface areas by planimeter measurements taken from aerial photographs on which estuanne boundaries at those tidal stages had been marked by direct observation. That agency has also compiled a tideland abstract listing the acreage of most Oregon estuary tidelands, as well as ownership and deed information.

Log-processing and shipping centers in Oregon are located in nine major areas that have an impact on aquatic environments: Coos Bay, Umpqua River mouth, Siuslaw Bay, Yaquina Bay, Tillamook Bay, Youngs Bay, the Columbia River estuary, the Columbia River between its mouth and Bonneville Dam (Portland), and the Willamette River around Oregon City. Currently, about 35 percent of tne 7 billion board feet per year are towed in these areas. The trends in intensity of use are reflected in figure 5. Coos Bay has two pulp mills and a large lumber- and log-shipping facility. From 1935 until

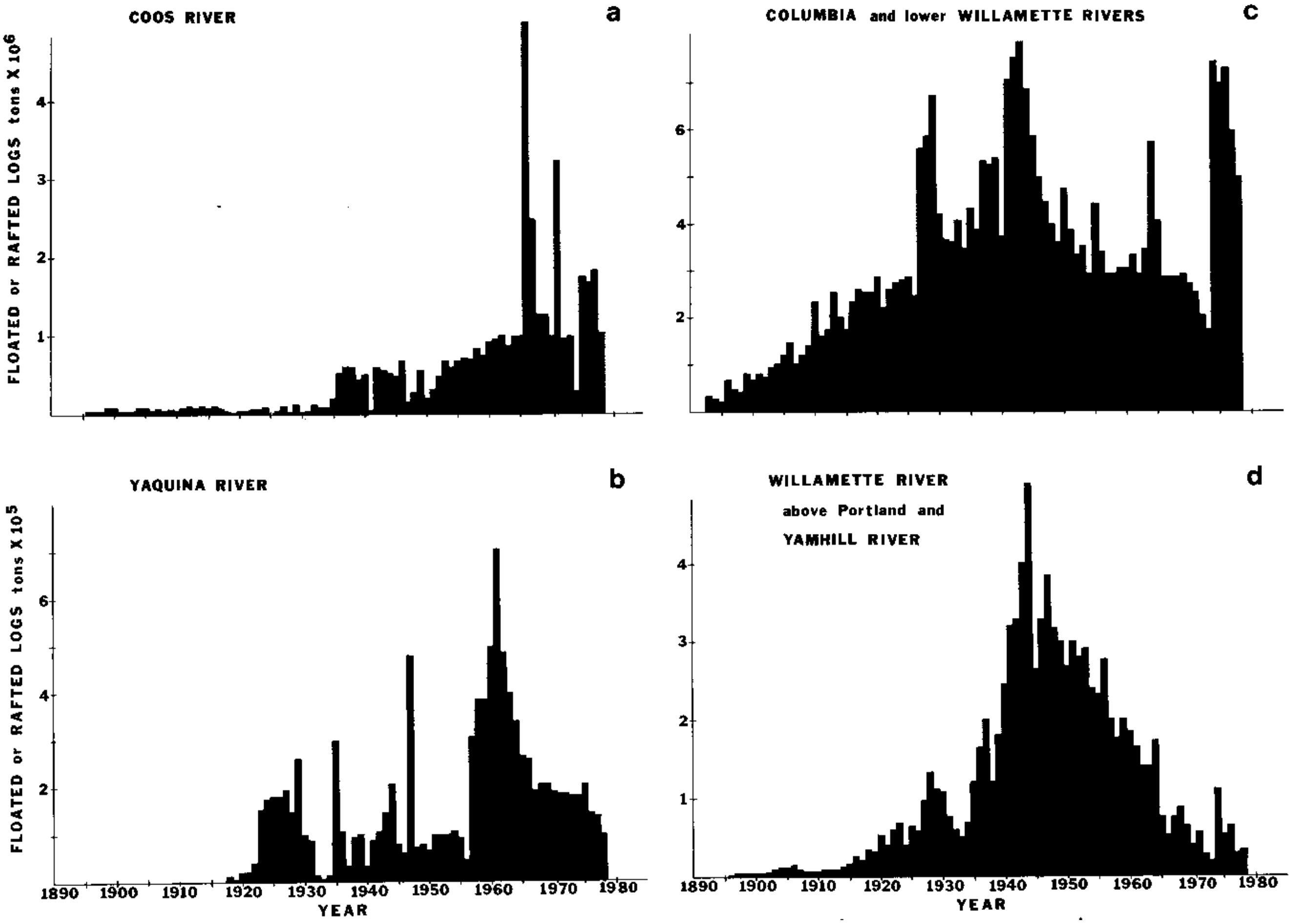


Figure 5.—Amount of logs floated or rafted on Oregon rivers, a. Coos River, 1895-1978; _b. Yaquina River, 1918-1978; . Columbia and lower Willamette Rivers, 1893-1978, d. Willamette River above Portland and Yamhill River, 1896-1978.

the present, the volume of logs towed in the bay generally ranged between 200 and 600 million board feet annually (fig. 5a). Yaquina Bay (fig. 5b) reflects a late start on the coast because of a forest fire in the 1860's. The Georgia Pacific Pulp Mill went into production in 1957, and the log flow increased three-fold. From 1962 until the present, use of the bay has declined because of decreased logging production and more dry-land sorting and storage in response to environmental regulation.

The Columbia and Willamette rivers were used before 1890. Records show a steady increase in log traffic in the Columbia River (fig. 5c), which peaked during World War II (WWII) and then declined until the housing boom of the mid-1970's when the first cutover land along the lower Columbia started to yield its second crop. Generally, between 1 and 2 billion board feet of lumber per year have been towed on the Columbia River since 1930. The mills at Longview and Portland at the mouth of the Willamette were and are major lumber centers, although Longview is a much more important center today. Logs from the early timber cutting in the Willamette River Basin were in large part transported down the Willamette to these Portland-area mills. The logs transported in the Willamette River essentially supplied the lower Columbia with logs from 1938 to 1957 (fig. 5d) as the peak of the Columbia production passed.

The U.S. Army Corps of Engineers prepared a map in 1935 (fig. 6) that showed the potential log traffic through the Oregon City Locks from the Willamette Basin to Portland and Columbia River sawmills. It greatly underestimated the potential traffic.

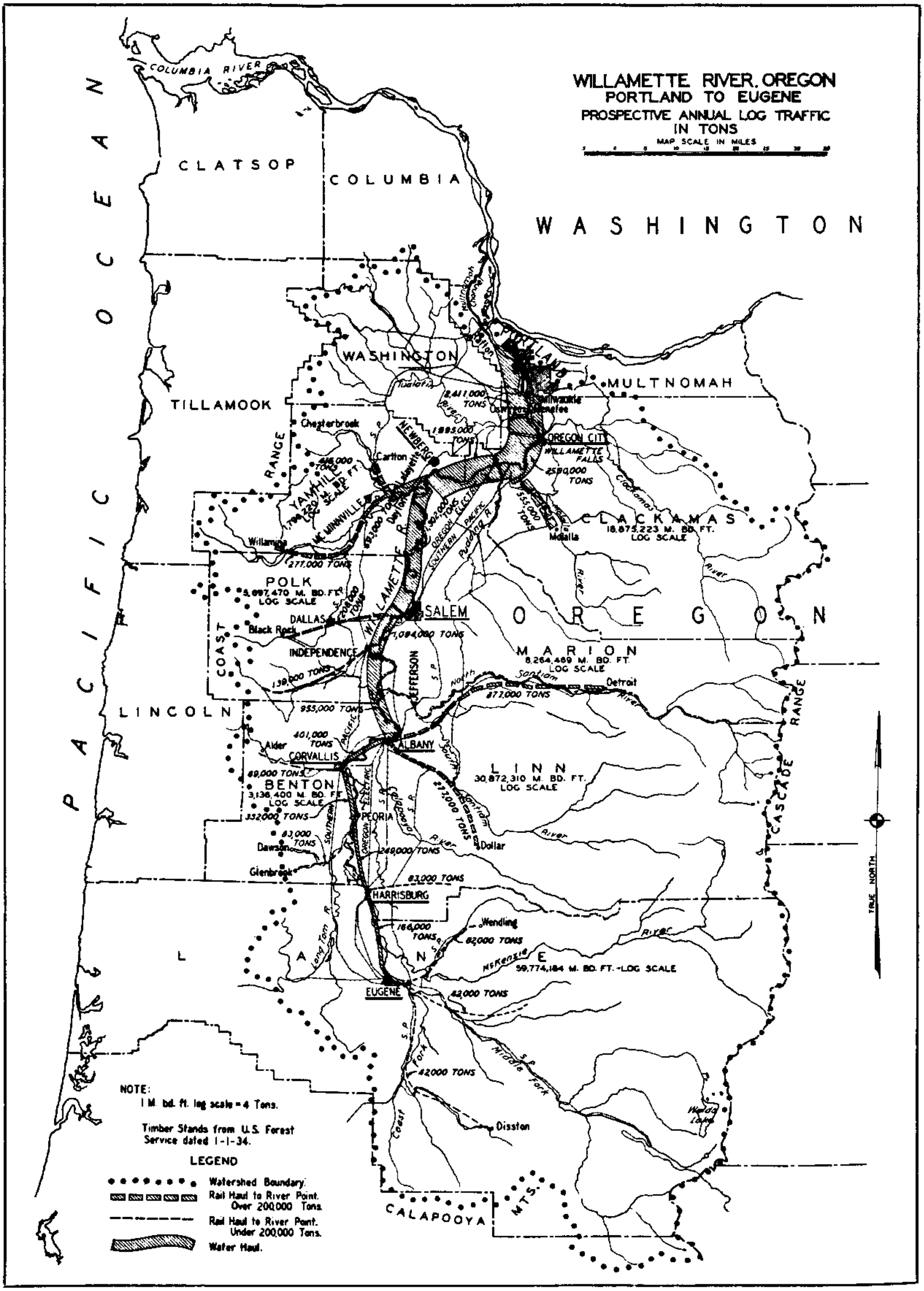


Figure 6.—In 1935, the U.S. Army Engineers prepared this map to show the potential log traffic through Oregon City locks, from the Willamette Basin to Portland and Columbia River sawmills. It greatly underestimated the potential traffic (U.S. Army Corps of Engineers 1937).

Major log-dump sites and storage sites are shown on this map. During WWII, over 1 billion board feet were annually transported down the Willamette River. This activity ceased as processing centers moved closer to the supply of logs (Cornwall 1941).

WASHINGTON

In Washington, the Columbia River, Puget Sound, and Grays Harbor are the principal areas affected by log handling. Simenstad and others (1982) identified 96 coastal and inland estuaries in 14 regions of the State (table 10). Estuaries within these regions are structurally, hydrologically, and biologically diverse, and range in size from drowned river valleys, which characterize major estuaries (for example. Grays Harbor and Skagit Bay/Port Susan) to the numerous small stream-channel estuaries characteristic of Puget Sound, Strait of Juan de Fuca, southeastern Alaska, and mucti of British Columbia. One region, the island archipelago of northern Puget Sound, has no major estuaries, but is greatly influenced by freshwater outflow from the Fraser (British Columbia) and Skagit rivers.

Like most west coast estuaries, Washington's have undergone extensive changes since the area was first settled. These changes were either directly to the natural estuarine environment or indirectly through alteration of freshwater habitats by log drives, urbanization, and diking in their contributing watersheds. Currently, the U.S. Army Corps of Engineers removes 2.3 million m-^{3} of sediments annually from Washington estuaries as part of maintenance dredging operations, nearly half of this from Grays Harbor (cited in Simenstad and others 1982). Although changes in most west coast estuaries have not been quantified, Bortleson and others (1980) nave reported changes in 11 major estuaries of Puget Sound. Such estuaries as the Duwamish and Puyaliup River deltas have lost essentially all their original wetland habitat. Although most smaller, less-urbanized estuaries in both Oregon and Washington escaped such devastation, most now have road causeways or dikes that usually altered the natural estuarine hydraulics. Thus, assigning a cause to a biological impact is extremely difficult. Quantitative information relating changes in estuarine habitats to changes in populations of salmonids and other estuarine fishes is distinctly lacking (Dorcy and others 1978, Simenstad and others 1982).

Table lO—Principal estuaries in Washington State, not including the Columbia River; data sources were Smith and others (1977), U.S. Army Corps of Engineers (1976), U.S. Geological Survey (1978, 1980), and Williams and others (1975)

Estuarine region	Estuaries	Principal watersheds	Orainage area	Average annual discharge	Annual maximum di scharge	Extant estuarine area[1]/	Water-inventory areas[2]/
			(km^2)	(hn^yr-^{1})	(n^sec-^{1})	(km2)	
North Sound	Drayton Harbor	Dakota Creek	75	››	--		01. 03 (part)
		California Creek	59	--	--	--	
	Bellingham Bay	Nooksack River	2139	3520	1060	13	
	Samish Bay	Sam'sh River	275	—	47	15	
North Puget Sound	Port Townsend Bay	Chimacum Creek	B7	--	--	--	02, 06 (part), 03 (part)
Skagit Bay/ Port Susan	Skagit Bay	Skagit River	8011	14900	4080	67	04, 05, 06 (part)
	Port Susan	Stillaguann'sh River	1772	2650	1785	24	
Possession Sound	Everett Harbor	Snohomish River	4439	8890	3260	19	07
Central/South	Shilshole Bay	Cedar River	487	625	250		08, 12, 14, 15 (part)
Puget Sound		Lake Washington	62	50	33	n.a.	
		Sammai'rish Lake	472	330	80	n.a.	
	Chambers Bay	Chambers Creek	48	—	--	--	
	Oyster Bay	Kennedy Creek	53	--	520	--	
	Skookum Inlet	Skookum Creek	--		--	--	
	Oakland 3ay	Goldsborough Creek	--		--	400	
	Hamnersley Inlet	Mill Creek	--		--	--	
	Case Inlet	Rocky Creek	--		--	--	
		Coulter Creek	--		--	--	
		Sherwood Creek	--		--	--	
	Burley Lagoon	Burley Creek	--		--	—	
	Gig Harbor	Crescent Creek	--		--	--	
	01alla Bay	01alla Creek	--		--	--	
	Sinclair Inlet	Gorst Creek	--	--	--	--	
	Dyes Inlet	Clear Creek	--	--	--	--	
		Strawberry Creek	--	--	--	--	
		Chico Creek	--	--	--	350	
	Liberty Bay	Dogfish CreeK	--	--	--	--	
	Miller Bay	Grovers Creek	--	—	--	--	
	Port Ludlow	Ludlow Creek	--	--	--	--	
Elliott Bay	Elliott Bay	Duwamish River	1140	1370	375	0.1	09
Commencement Bay	Commencement Bay	Puyaliup River	2455	3010	1610	0.1	10
Nisqually Reach	Misqually Reach	Hisqually River	1339	1630	870		11
		McAHister Creek	--	--	--	--	10
Budd Inlet	Capitol Lake	Deschutes	417	--	3380	--	13
Hood Canal	Lynch Cove	Union River	61	--	--	--	15 (part), 16, 17
	Big Mission Creek	Big Mission Creek	--	--	--	—	
	Tahuya River	Tahuya River	--	--	--	--	
	Annas Bay	Skokomish River	622	655	610	6.0	
	Dewatto Bay	Dewatto River	43	--	750	--	
	Lilliwaup Bay	Lilliwaup Creek	--	--	--	--	
	Hamma Hamiiia River	Hamma Hamma River	219	--	2260	--	
	Anderson Cove	Anderson Creek	--	--	--	--	
	Duckabush River	Duckabush River	172	370	255	--	
	Dosewallips River	Dosewallips River	--	--	--	--	
	Quilcene Bay	Big Quilcene River	--	--	--	--	
		Little Quilcene River					
	Jackson Cove	Harple 3reek	--	--	--	--	
		Spencer Creek	--	--	--	--	
	Tarboo Bay	Tarboo Creek	32	,--	--	--	
	Thorndyke Bay	Thorndyke Creek	31	--	--	—	
	Stavis Bay	Stavis Creek	--	--	--	--	
	Seabeck Bay	Seabeck Creek	--	--	--	--	
	Little Beef Harbor	Little Beef Creek	--	--	--	--	
	Big Beef Harbor	Big Beef Creek	36	35	20	--	
	Port Gamble	Gamble Creek	--	--	--	--	
		Miller Lake	--	--	--	--	
	Squamish Haroor	Shine Creek	--	--	—	--	

See footnotes at end of table.

Table 10—Principal estuaries In Washington State, not including the Columbia River; data sources were Smith and others (1977), U.S. Army Corps of Engineers (1976), U.S. Geological Survey (1978, 1980), and Williams and others (1975) (continued)

Estuarlne region	Estuaries	Principal watersheds	Drainage area (km2)	Average annual d1scharge (hn^yr-^{1})	Annual maximum d1scharge (n^sec-^{1})	Extant estuarine area!^{7} (km2)	Water-inventory areasi/
Strait of Juan de Fuca	Discovery Bay	Snow Creek	--	--	50		18, 19
		Salmon Creek	49			-	
	Sequim Bay	Jimmycomelately Creek	—				
		Dean Creek	--	--	--	--	
	New Dungeness Bay	Dungeness River	513	350	195	7	
	Fresh Water Bay	Etwha River	813	1340	1180	--	
	Lyre River	Lyre River	171	—	—	—	
	Pysht River	Pysht River	115	--	--	—	
	Clallam Bay	Clallam River	82	—	—	—	
	Hoko River	Hoko River	113	--	3620	--	
	Sekiu River	Sekiu River	85	—	—	—	
	Sail River	Sail River	14	--	20	--	
North Coastal	Mukkaw Bay	Waatch River	33	—	35		20, 21
		Sooes River	106	--	95	--	
	Ozette River	Ozette Lake/River	229	—	45	—	
	Quillayute River	Quillayute River	1629	--	—	--	
	Goodman Creek	Goodman Creek	82	--	—	--	
	Hoh River	Hoh River	774	2240	1300	--	
	Kalaloch Creek	Kalaloch Creek	--		—	--	
	Queets River	Queets River	1153	3690	3690	--	
	Raft River	Raft River	197	--	490	—	
	Quinalt River	Lake Quinault, Quinalt River	1124	2520	1420	--	
	Moclips River	Moclips River	91	--	120	--	
	Copalis River	Copalis River	--		--	--	
Grays Harbor	Grays Harbor	Humptulips River	337	1190	935	—	22
		Hoquiam River	234	--	--	--	
		Wishkah River	117	--	--	136	
		Chehalis River	5358	6670	1570	—	
		Johns River	81	--	-	-	
		Elk River	47	--	--	--	
WHtapa Bay	Willapa Bay	Cedar River	33	--	--	--	23
		North River	827	860	990	--	
		Wi11apa River	668	590	325	--	
		Niawiakum River					
		Palix River	95	--	--	167	
		North Nema River	56	105	55	—	
		South Nema River	47	--	65	—	
		Nasene River	142	385	315	—	
		Bear River	60	--	21	--	

-- = no data available.

n.a. 5 not applicable

y Combined subaerial and littoral wetlands.

y **See** Williams and others (1975) for description of water-inventory areas.

The volume of logs rafted in the Cowlitz River (fig. 7a) reflects log drives and the pattern of Washington's annual timber harvest until the depression in 1929. Since WWII, the use of the Cowlitz to transport or store logs has dropped to nothing, because of dry sorting and increased use of long truck hauls directly to the mill. The log activity in the Lewis River (fig. 7b) represents the era of log drives and river booming from 1900 to 1920. The big increase in rafted logs since 1957 represents storage for a pulp and paper mill at St. Helens, across the Columbia River in Oregon. About 40 million board feet per year are rafted in and out of the first 6.4 km of the Lewis River. Grays Harbor (fig. 7c) totally reflects the annual Washington log-production curve until the 1940's, when the old-growth timber was gone and the second-growth timber was not yet being harvested. In the mid-1970's, major changes to dry-land sorting and environmental regulations drastically reduced the number of logs rafted in the bay feeding the two pulp mills. For 40 years, between 1920 and 1960, the volume of logs in general was

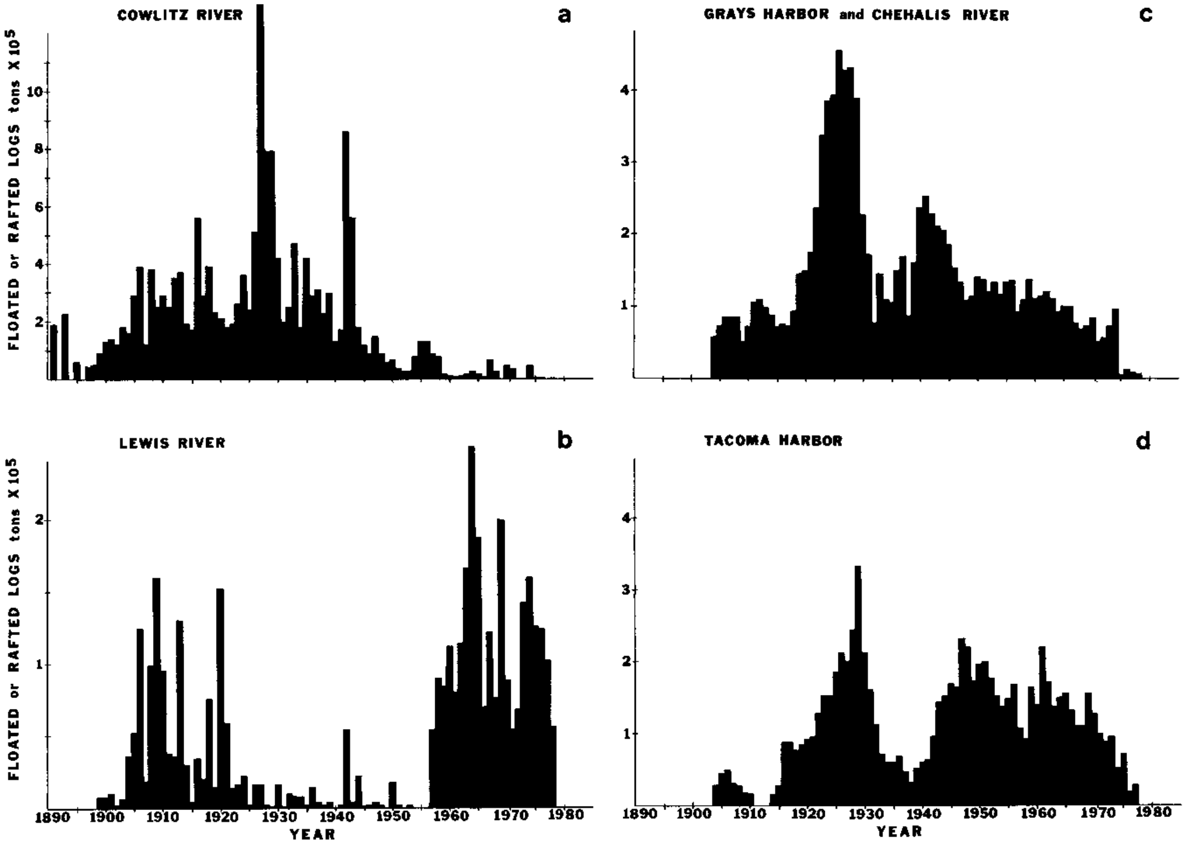
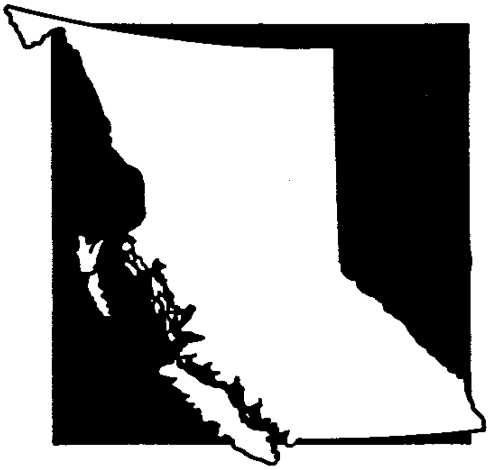


Figure 7.—Amount of logs floated on Washington rivers, a Cowlitz River, 1890-1978; b^. Lewis River, 1899-1978; ^. Grays Harbor and Chehalis River, 1904-1978; d. Tacoma Harbor, 1904-1978.

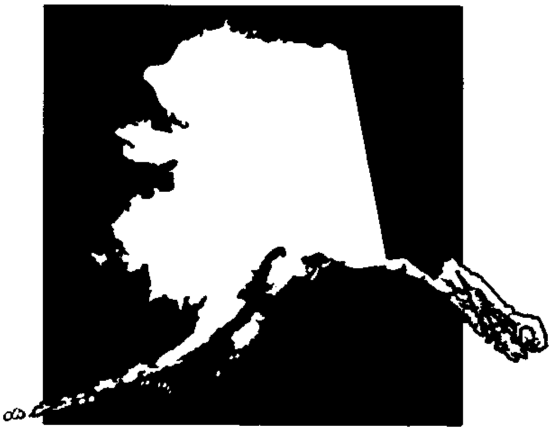
1/2 billion board feet annually. Tacoma Harbor (fig. 7d) also averaged 400 million board feet per year. Lake Washington, in Seattle, became a major route for rafted logs to Puget Sound mills when the Montlake Ship Canal was completed in 1916. Billions of board feet of logs were towed across the lake and through the canal. Presently, over 100 million board feet per year still traverse the lake and ship canal.

In the early days, 100 percent of the logs were transported by water. Grogan (1924) estimated that 60 percent of the logs that supplied the sawmills on Puget Sound and the Columbia River were transported either all or most of the way from the woods to the mill by water (about 5 billion board feet). Towing distances were between 160 and 320 km and the rafts were flat, not bundled; hence, many logs were lost, although in those days only prime Douglas-fir and western redcedar were used.



BRITISH COLUMBIA

The coastal harvest of British Columbia timber is greater than 7 billion board feet annually (Ainscough 1979). The most economical means of transporting logs from the forests Co the mills is by marine waterways, large interior lakes, and the Eraser River system. Boyd (1979) and Cottel (1977), estimated Chat about 90 percent of the coastal timber harvest is placed in the water during part of its transportation to processing areas. Boyd (1979) has documented regional differences in the production, species, and modes of log transport within the coastal British Columbia forest industry during 1978.



ALASKA

Alaska, like British Columbia, totally depends on water to move logs to four major processing centers: Wrangell, Petersburg, Sitka, and Ketchikan. The number of estuaries in Alaska has been reported as between 1,000 and 22,000, depending on how "estuary" is defined. Obtaining an accurate number is difficult because of the large glacial bays (fjords), with numerous tributaries entering them (Paris and Vaughan 1985). Some people consider each tributary an estuary; others would use the term for the whole bay. In 1976, John Blankenship of the U.S. Fish and Wildlife Service calculated the area of all estuaries 40.5 ha or larger for the Tongass National Forest (table 11). The areas were planimetered from 1-inch-to-the-mile topographic maps. The total area of each estuary, and the area within each estuary that was 18 m or less in depth, were recorded. The areas were summed to obtain total estuarine area and shallow estuarine area (Paris and Vaughan 1985). Glacier Bay, upper Lynn Canal, and Annette Island were not included in the measurements because they are not part of the Tongass National Forest.

Table 11—Total estuanne area for Tongass National Forest, southeastern Alaska

Area	Total estuarlne area	Estuarine area less than 18 m deep	Area less than 18 m deep
	Hectares	Hectares	Percent
Chatham	326 854	126 383	39
Stikine	137 441	91 157	66
Ketchikan	172 462	79 907	46
Total	636 757	297 447	47

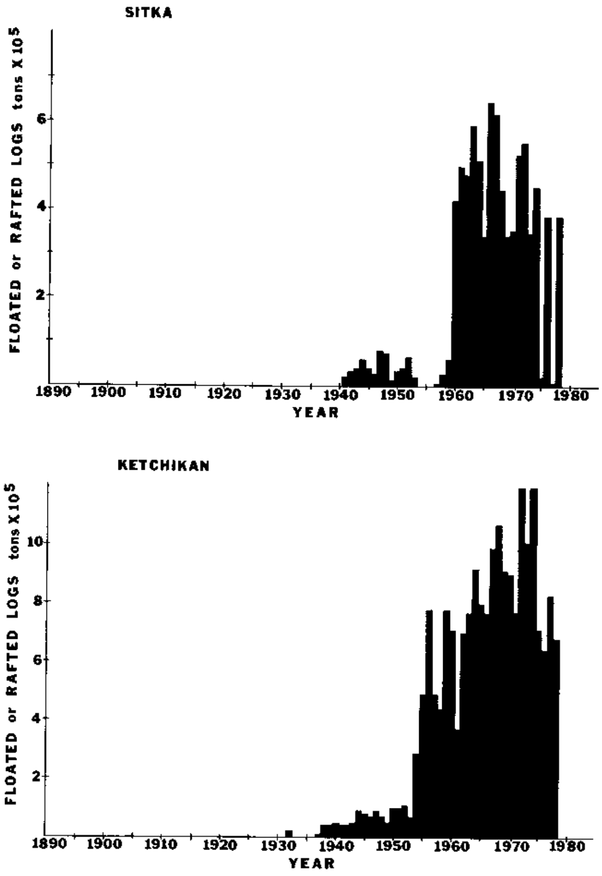
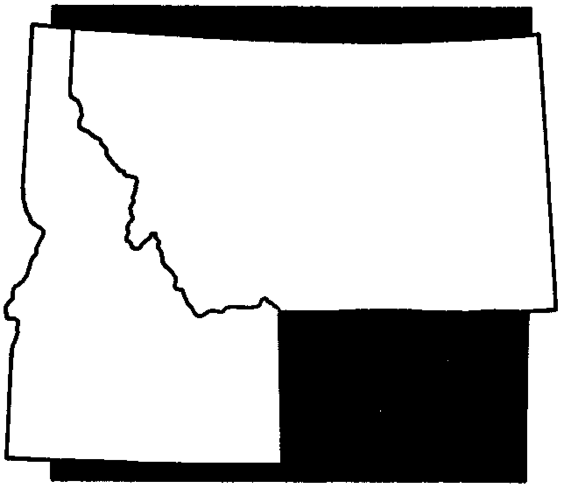


Figure 8.—Amount of logs floated or rafted to Sitka, 1940-1978, and Ketchikan, 1932-1978, Alaska.

Logs rafted to the Ketchikan and Sitka pulp mills are shown in figure 8. Not much logging was done until pulp mills opened in Ketchikan in 1954 and in Sitka in 1959. Since these openings, Ketchikan has annually received 200 Co 300 million board feet of logs and Sitka has averaged slightly more than 100 million board feet annually. The total Alasfca timber harvest peaked at 570 million board feet in 1970 and will probably not exceed 750 to 900 million board feet per year in the best of times. Its total estuarine area exceeds the estuary area of British Columbia because of the numerous islands.



IDAHO AND MONTANA

Large numbers of logs have been and continue to be rafted down the St. Joe River, across Coeur d'Alene Lake, and down part of the Spokane River (fig. 9). Log volumes peaked in the 1920's and since then have sustained an annual rafted volume of about 100 million board feet. Lakes and rivers that received the transported logs in the past are: Flathead Lake, Montana (fig. 9a); Coeur d'Alene Lake and St. Joe River (fig. 9b); Pend Oreille River, between Priest River, Idaho, and lone (fig. 9c); and Priest River (fig. 9d). Peak activity for all out Flathead Lake was in the 1920's. Flathead Lake mills served mines and railroads between 1905 and 1920.

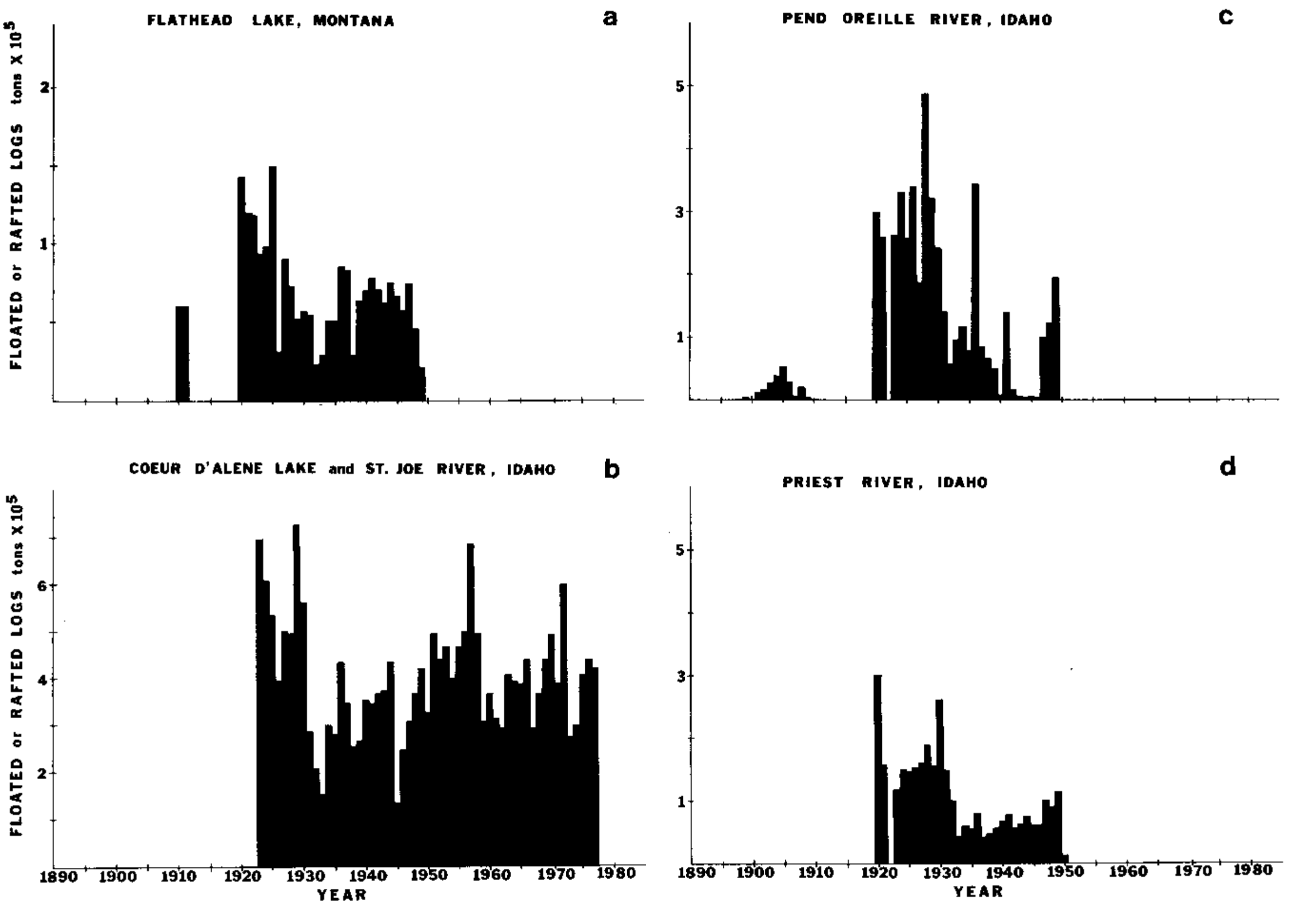


Figure 9.—Amount of logs floated or rafted on Montana "and Idaho waters, a_. Flathead Lake, Montana, 1910-1949; _b. Coeur D'Alene Lake and St. Joe River, Idaho, 1920-1950; c^ Pend Oreille River, Idaho, 1920-1949; d_. Priest River, Idaho, 1920-1950.

CALIFORNIA

California's waterways have carried logs for two centuries. Many streams in the redwood forests of Santa Cruz, Del Norte, Mendocino, and Humboldt counties experienced many log drives. The Sacramento River floated millions of board feet to mills located along its length. The records are almost nonexistent for volumes of logs handled in California estuaries. The principal estuaries used were San Francisco Bay, Los Angeles Harbor, and San Diego Harbor; they received hundreds of million board feet of logs shipped from Oregon and Washington. Humboldt Bay was too shallow to maintain a great volume of logs rafted in its waters, although it still rafts some logs near the mills. Most of California's bays are not located in timber country or are Coo small and rocky to have much log transportation.

EXTENT OF LEASED LOG-STORAGE ACREAGE AND VOLUMES OF LOGS HANDLED

Leased acreages for Oregon total 794 ha. Of this, 41 percent are in coastal estuaries and the remaining 59 percent are primarily on the Columbia and Willamette Rivers (table 12). In Washington, 934 ha are leased Co log handling, of which 85 percent are in estuaries (table 13).

Table 12—Total area of log-handling leases for Oregon

Waterways	Area	Portion of total area
	Hectares	Percent
Coastal:		
Necamcuin River	0.08	
Salmon River	.28	
Siletz River	.97	
Yaqinna Bay	16.81	
Yaquina River	30.33	
Sluslaw River	30.94	
Moan-ink Lake	2.03	
Siltcoos Lake	1.62	
Tahkemtch Lake	.41	
Smith River	3.77	
Umpqua River	104.65	
Umpqua and Smith Rivers	7.78	
dear Lake	.04	
Coos Bay	21.87	
Coos River	324.0	
Isthmus Slough	58.56	
Coquille River	2.11	
Cnetco River	.41	
Lake Ewanna	15.35	
Pacific Creek	.65	
Scholfield Creek	.30	
	622.96	59
Columbia and Multnomah Channel:		
Columbia River	170.0	
Westport Slough	.2	
Skipanon Slough	12.7	
Lewis and C1ark River	.7	
Scapoose Bay	1.66	
Multnomah Channel	128.3	
Oregon Slough	38.1	
Sandy River	--	
	351.66	33
willainette:		
Millamette River	56.9	
Tualatin River	--	
	56.9	5
Inland:		
Upper Klamath Lake	1.5	
Klamath Lake	.6	
Klamath River	4.5	
John Day River	.5	
Snake River	23.1	
	30.2	3
Grand total	1061.7	100

no data available.

Table 13—Total area of log-handling leases for Washington

Waterways	Area	Portion of total area
	Hectares	Percent
Coastal Washington:		
Willapa Bay and River	15	
Grays Harbor ana Chehalis River	120	
	135	14
Puget Sound:		
Anacortes		
^kagit Bay and River	141	
Seattle		
Snohomish	n	
Dabob Bay	34	
Port Angeles	109	
Tacoma Harbor, Puyaliup River	45	
Kitsap area	33	
Skokomish River (Hood Canal)	58	
San Juan Islands	9	
Olympia Harbor	100	
	540	58
Columbia River:		
Gray's "Bay Columbia Estuary	61	
Ketso/Longview		
Columbia River		
Cowlitz River (mouth)	145	
Lewis River; Vancouver, Washington	1	
Lower Columbia River	47	
Lower Columbia River Klickitat River	5	
	259	28
Grand total	934	100

British Columbia has 8956 ha under lease (table 14). A survey of 943 log-handling leases by FERIC (1980) indicated that the majority of British Columbia water leases are located in coastal rivers (29.0 percent), intertidal areas (22.1 percent), and deep-water environments (31.1 percent), although log-handling sites in estuaries tend to be larger than other leased areas because most processing sites are located there (table 14). Ainscough (1979) documented the locations of major log-sorting, dumping, booming, and processing sites along the south coast of British Columbia (fig. 10).

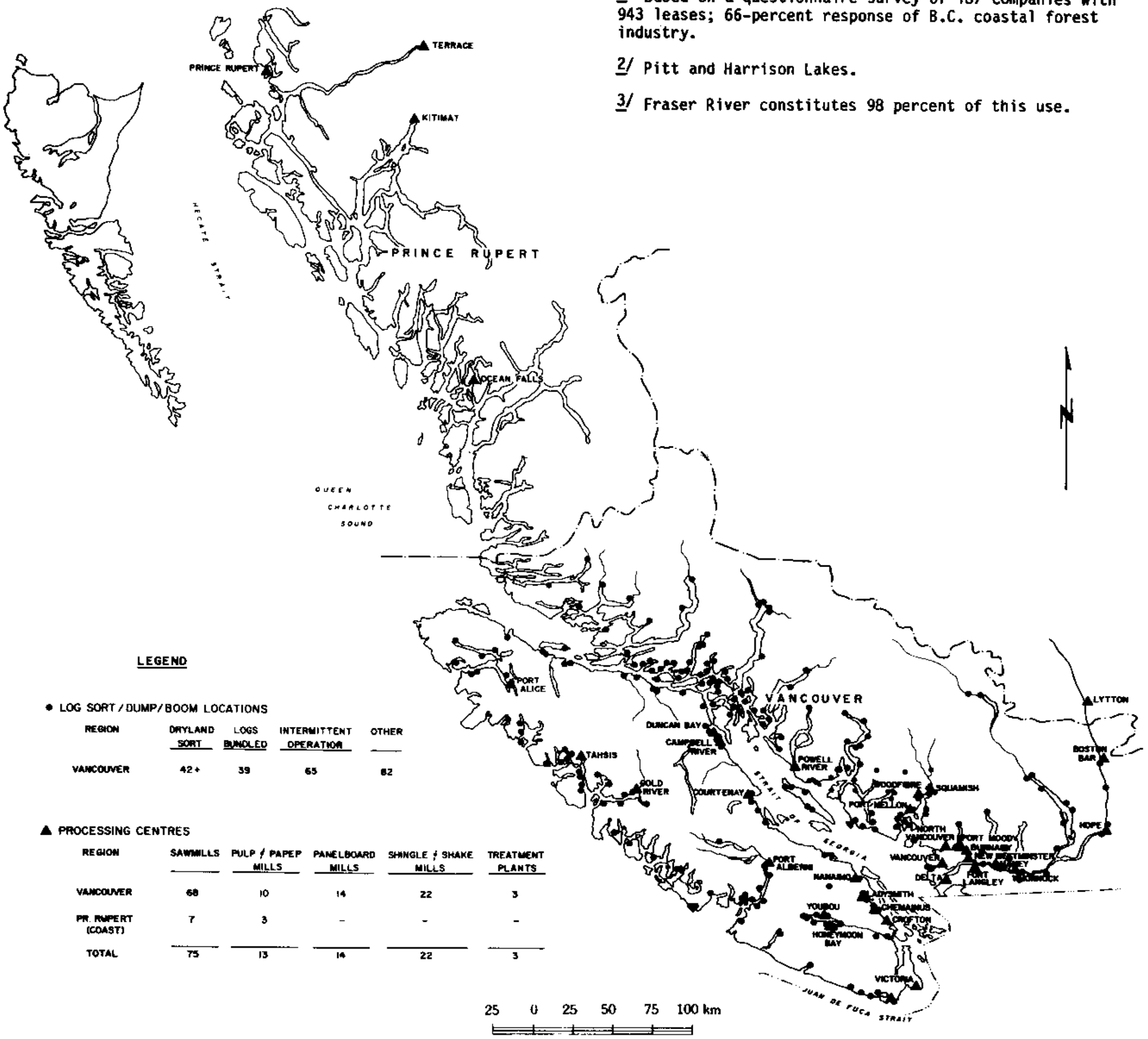
Table 14--Location and average size of coastal British Columbia log-handling leases[1] (FERIC 1980)

Location	Area	Portion of total leases	Average area
	Hectares	Percent	Hectares
Lake[2]	197.8	2.2	12.4
River[3]	1,200.2	13.4	6.3
Estuary	954.6	10.7	25.1
Intertidal	2,259.1	25.2	15.5
Deep water	2,997.0	33.5	14.5
River/estuary	50.9	0.6	25.5
Estuary/intertidal	164.3	1.8	16.4
Intertidal/deep water	1,083.5	12.1	22.6
Other combinations	48.8	.5	12.2
Total	8,956.2	100.0	

[1] Based on a questionnaire survey of 187 companies with 943 leases; 66-percent response of B.C. coastal forest industry.

[2] Pitt and Harrison Lakes.

[3] Fraser River constitutes 98 percent of this use.



LEGEND

● LOG SORT / DUMP / BOOM LOCATIONS

REGION	DRYLAND SORT	LOGS BUNDLED	INTERMITTENT OPERATION	OTHER
VANCOUVER	42+	39	65	82

▲ PROCESSING CENTRES

REGION	SAWMILLS	PULP / PAPEP MILLS	PANELBOARD MILLS	SHINGLE / SHAKE MILLS	TREATMENT PLANTS
VANCOUVER	68	10	14	22	3
PR. RUPERT (COAST)	7	3	-	-	-
TOTAL	75	13	14	22	3

Figure 10.--Log sorting, dumping, booming, and processing locations along the south coast of British Columbia.

The FERIC (1980) report indicated that the greatest proportion of log-handling water leases in coastal British Columbia were used for log storage, with relatively minor areas used for dumping, and to a lesser extent sorting (table 15). The information reported in this study has been considered representative of present Canadian coastal log-handling practices.

Alaska has 430 ha under lease, representing 89 log-transfer sites and 49 log-storage sites. Another 228 sites are proposed for log-transfer facilities and 12 sites are proposed for log storage (Faris and Vaughan 1985). Paris and Vaughan (1985) constructed a map showing processing plants; abandoned, new, and proposed dump sites; and abandoned, currently occupied, and proposed storage sites (fig. 11). They estimated that 0.01 percent of the total estuarine area is affected by bark accumulation adjacent to the log-transfer facilities and project that a worst case for the future would represent 0.04 percent of the estuarine total. Volumes of logs moved are not great in Alaska when compared with log-handling activity in British Columbia, Washington, and Oregon.

Table 15—Major uses of coastal British Columbia log-handling leases[1] (FERIC 1980)

Use	Area	Portion of area
	Hectares	Percent
Log dumping	204.2	2.3
Barge dumping	132.6	1.5
Barge loading	205.6	2.3
Log sorting/booming	1,312.0	14.7
Log bundling	86.0	1.0
Log storage	5,696.1	63.6
No present use	796.4	8.9
Other	522.9	5.8
Total	8,955.8	100.0

[1] Based on a questionnaire survey of 187 companies with 943 leases; 66-percent response of B.C. coastal forest industry.

Hermann (1979) has calculated the effects of log-rafting sites on benthic invertebrates and fish production in the entire Coos Bay, Oregon, estuary. He estimated summer benthic invertebrate biomass of 85 ha of intertidal log-storage areas to be 2050 kg (dry weight). This was compared to his estimate of 64 370 kg and 257 000 kg for the benthos on the upper bay and entire Coos Bay tideflats, respectively. He further stated that the 2050 kg of benthos could produce about 1370 kg (live weight) of fish tissue. This amounted to about 0.6 percent of his estimated fish production of the entire Coos Bay tideflats (Hermann 1979).

When the activity per hectare leased is compared to total estuary available (table 16), log handling—although occupying sensitive intertidal zones--impinges on less than one tenth of one percent of the estuary area available. Guidelines are in effect to minimize the impacts by limiting site location. Log transportation directly affects estuaries in British Columbia much more than in Alaska, Washington, and Oregon. British Columbia has also spent more money and time analyzing and researching the problem than has any other area.

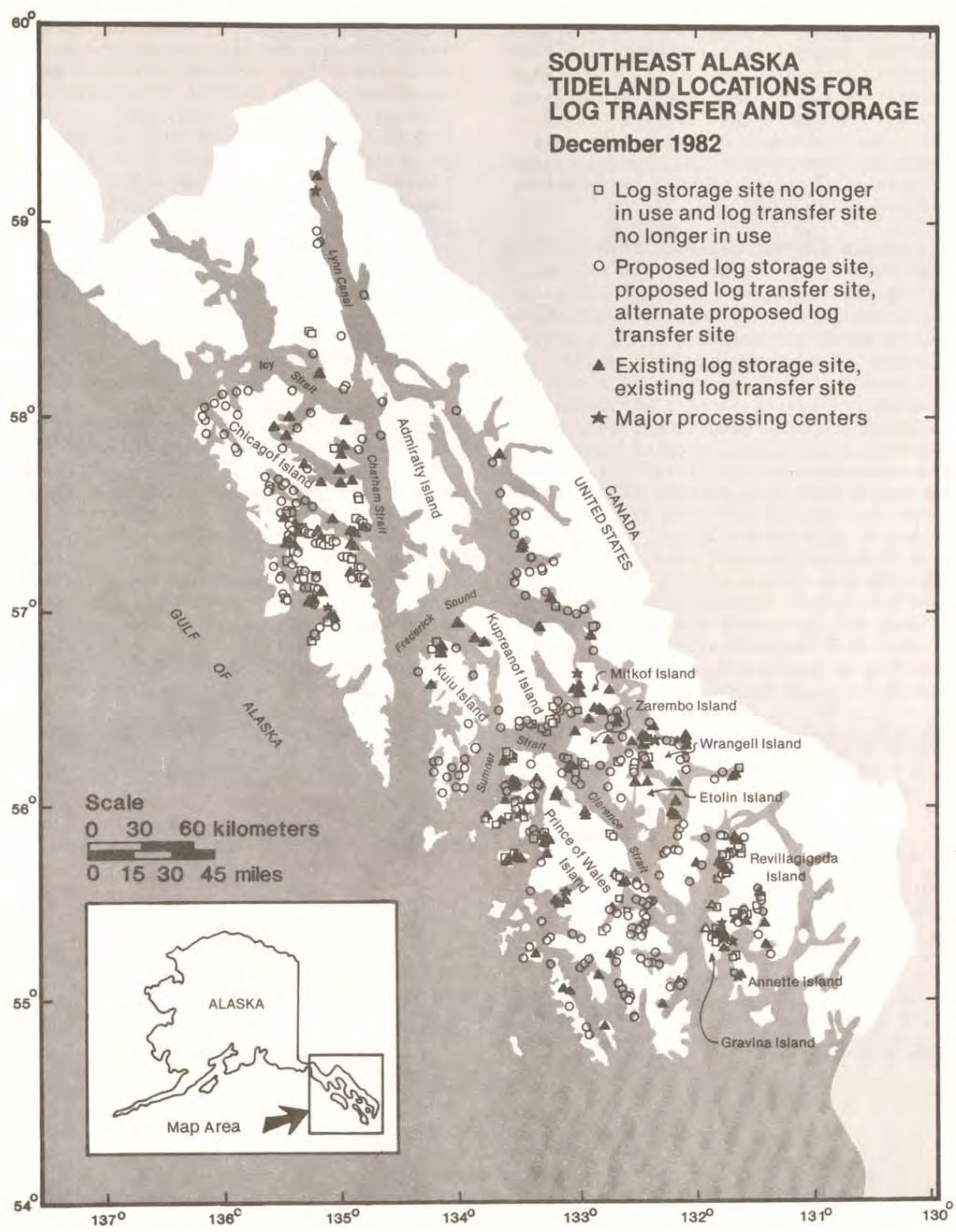


Figure II.—Tideland locations for log transfer and storage, southeast Alaska, 1982. From Faris and Vaughan (1985).

Table 16—Comparison by State and Province of log-handling leases, area affected, and board feet of logs transported

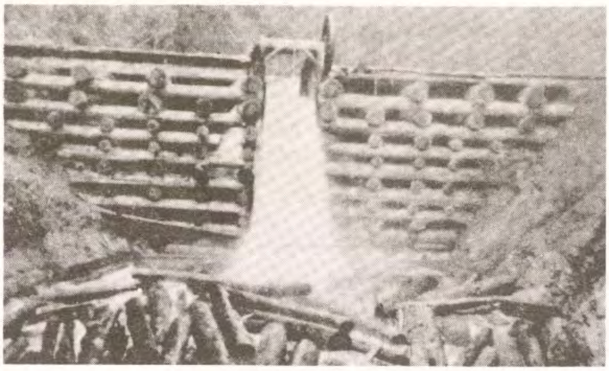
State/Province	Number of sites leased	Number of hectares leased	Estimated board feet of logs transported *or* stored X 10°
Southeastern Alaska	81	430	400
British Columbia	943	8956	6.030
Washington	154	943	4,000
Oregon	100	794	3,500

Although data show that only a small fraction of the total available estuarine area might be affected, a strong rationale remains to attempt to locate that fraction on the least damageable portion of the available estuary. The fact that only a small amount of total estuarine area may be involved in log-transfer activities should not be used as an excuse to avoid the responsibility of minimizing or reasonably mitigating damages at individual sites. Paris and Vaughan's (1985) conclusion underscores the fact that available data are just now providing some understanding about the role of certain areas of the estuary in salmon production. Even though a large proportion of the original marshlands and intertidal areas have been lost in California, Oregon, Washington, and British Columbia, how this has affected salmon runs is impossible to say. We do not know whether the amount of intertidal and marsh area is approaching some lower limit critical to the survival of the present salmon production. All along the western Pacific coast, from California to central Alaska, major investments are being made to enhance salmon runs, and we do not know whether the intertidal estuaries and marshes are adequate or needed to support the increased numbers. Clearly, the consequences of allowing estuarine areas to be destroyed are highly uncertain and could put valuable salmon runs in jeopardy. This uncertainty about the importance of estuarine areas to salmon is likely to persist in the immediate future, despite the best research efforts. The estuarine and marsh areas and the salmon systems associated with them are complex and large. Added to this is the relatively long life cycle of the salmon, taking as many as four or more years before the adult returns through the estuary. These characteristics make the research task difficult, lengthy, and costly. Currently, our technology and organization of research is poorly developed to meet the challange.

Planning for log transportation--whether floating or land-to-barge systems—as well as for other competing developments, must consider this continuing uncertainty. Guidelines for ecological-impact assessment must be designed so that the information required reflects what can reasonably be developed in a short time and does not falsely imply that impacts on salmon can be measured in a short time.

INFORMATION GAPS AND RESEARCH RECOMMENDATIONS

An extensive amount of information is available on certain aspects of log handling and storage. Most studies have concentrated on bark loss, benthic habitat alteration, benthic organisms, leachates, and grounding effects. This information has been used to establish corrective regulations and policies. Most fisheries biologists, ecologists, environmentalists, and conservationists—as well as much of the public--would answer yes to the question: "Is log transfer and storage detrimental to the estuary and salmonid species?" Most believe that estuaries are essential



components t.o survival of salmon stocks of the Pacific Northwest and that any disturbance to the estuary is detrimental, no matter how small the area affected.

From our review of the literature, we conclude that evidence is inconclusive on the importance of the small areas impacted by log transfer and storage Co overall production and population success of bivalves, crabs, or salmonids. Log-transfer sites and estuarine ecosystems vary greatly and, with the present status of knowledge, evidence from one estuary must be applied with great care to another.

Information gaps exist; for example, knowledge is inadequate on the availability 'and the quality of alternative habitats for salmonids and other species. Such information is essential Co evaluate the importance of present and proposed log-transfer and storage sites to the species of interest. Would organisms--fish, for example—congregate in the remaining log-transfer site in an estuary or would they occupy other estuarine or coastal habitats? In those alternative habitats, would fish have comparable survival rates, or would their survival be poorer? The same questions need to be answered for crabs and mollusks.

Dry-land alternatives to freshwater or marine log transfer and storage may present irreversible alterations to upland habitats or permanent structures that can displace the marine habitat with pilings and rock fill. On-shore storage and handling of logs, although protecting the marine habitat, can permanently change the shoreline and present a different set of bark-disposal problems (Forest Engineering Incorporated 1982).

Avifauna and marine mammals use log rafts as feeding and resting stations, and as nesting spots. Older rafts in fresh water with brush growing on them may be used for breeding and nesting. Both the avifauna and marine mammals are significant components of the ecosystem; the relation between these organisms and log rafts, including consequences of raft removal, should be studied. The incidence of usage of log rafts by mammals should be determined.

Except for cursory observations, the significance of using log rafts as habitat or protective cover by fish has not been well documented. We need to determine whether storage and dumping areas provide significant habitat for fish, or if certain species avoid the rafts because of leachates or other factors. Studies could be limited to determining whether fish abundance and distribution are influenced by the rafts and dumping activities. Emphasis should be placed on sloughs and backwater areas where flushing action is minimal and where leachate concentrations are expected to be greatest.

When sunken logs are retrieved, the benthic habitat is disturbed. Maintenance dredging of log-dumping areas, and the disturbance of bottom sediments by tugs and other log-handling vessels may cause similar effects. The significance of this disruption has not been documented or quantified. Because of the potential for negative impact (such as resuspension of toxic materials or damage to benthic habitat) compared to the positive impact of retrieving salvageable logs, an examination should be made of the extent of **area** affected by retrieval operations, maintenance dredging, and the activities of vessels in log-handling areas.

In general, less emphasis should be placed on studying impacts that have already been described, because regulations are in effect or are being developed to alleviate them. Both positive and negative impacts not previously studied should be given more emphasis, particularly relative to their effect on the whole ecosystem. Research priority should be given to areas of poor water circulation, because effects would be greatest in these areas.

RECOMMENDED PRACTICES

The following protective measures, based on a Task Force Report on Log Storage and Rafting in Public Waters (Hansen and others 1971) (approved by the Pacific Northwest Pollution Control Council), were designed to minimize the impacts of log handling on the aquatic environment; they are still applicable today:

- Dry-land handling and sorting is preferred to water handling and sorting, although the location of dry-land facilities should not be in fisheries-sensitive zones, such as estuaries, salt marshes, herring spawning areas, or shellfish beds.

- The free-fall, violent dumping of logs into water should be prohibited, because this is the major cause and point source of loose bark and other log debris.

  Easy let-down devices should be used to place logs in the water, thereby reducing bark separation and generation of other wood debris.

- Positive bark and wood-debris controls, collection, and disposal methods should be used at log dumps, raft-building areas, and millside handling zones for both floating and sinking particles.

- Log dumps should not be located in rapidly flowing waters or other zones where positive bark and debris controls cannot be effective.

- Accumulations of bark and other debris on the land and docks around dump sites should be kept out of the water.

- Whenever possible, logs should not be dumped, stored, or rafted where grounding, particularly on sensitive habitats, will occur.

- Where water depths will permit the floating of bundled logs, they should be secured in bundles on land before being placed in the water. Bundles should not be broken again except on land or at millside.

- The inventory of logs in water for any purpose should be kept to the lowest possible number for the snortest possible time.

More site-specific measures can be applied Co a particular operation to ensure protection of aquatic habitat (Toews and Brownlee 1981), based on the specific resources present and the details of the operation. A technical assessment of a log-handling proposal might therefore include the following considerations:

- Site sensitivity and uniqueness

  Resource values present (for example, shellfish, herring spawn, emergent vegetation, salmonid rearing).

  Physical characteristics of site (for example, substrate, depth, currents, tidal flushing).

- Details of proposal

    Dumping, sorting, transport methods.

    Log volumes and inventory, seasonal log flow.

    Duration of operation (usually related to upland logging).

    Positive debris-control measures (recovery and disposal of both floating and sinking debris)*

- Potential impacts based on above considerations for both proposed and alternate sites (alternate sites may include those on dry land).

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APPENDIX

Total timber produced (thousand board feet) in the western United States, 1869-1946

Year	Oregon	Washington	California	Idaho	Montana
1869	75.193	128,743	3,530.842	1,490	12,571
1879	177,171	160,176	326,340	18,204	24,420
1889	462,620	1,160,023	528,554	30,933	93,314
1899	734,538	1,429,032	737,760	65,363	255,685
1904	987.107	2,485,628	1,088,788	211.447	236,430
1905	1,262,610	3,917,166	1,061,608	212,725	189,291
1906	1,604,894	4,305,053	1,348,359	418,944	328,727
1907	1.635,563	3,777,606	1,350,887	513,788	343,814
1908	1,468,158	2,915,928	1,005,515	518,625	311,533
1909	1,898.985	3.862,916	1,154,007	645.800	308,582
1910	2,084,633	4.397,492	1,265,876	745,984	319,089
1911	1,803,698	4,064,754	1,218,838	765,670	228,416
1912-	1,916,160	4,099,775	1,223,259	713,575	272,174
1913	2,098,467	4,592,053	1,201,957	652.616	357,974
1914	1,817,875	3,946,189	1,318,065	763,508	317,842
1915	1,505,633	3,726,343	1.119,458	770,031	324,333
1916	2,221,854	4.492,997	1,413,541	846,107	383,884
1917	2,485,783	4,304,449	1,417,068	749,764	347,496
1918	2,708,955	4,602,469	1,277.084	802,529	335,811
1919	2,577,403	4,961,220	1,279,698	765,388	287,378
1920	3,316,098	5.524,509	1,482,102	969,576	409,667
1921	2,022,219	3,831,800	1,360,514	542,620	216,989
1922	3,023,768	5,836,277	1,720,556	857,581	303,458
1923	3,966,083	6,677,656	2,118,094	1,072,930	426,917
1924	3,665,547	6,267.343	1,996,496	1,017,960	350,335
1925	4,216,383	7,027,325	2,042,991	1,140,575	388,854
1926	4,454,735	7,546,239	2,187,959	947.471	378,698
1927	3,972,852	7,325,862	2,070,811	823,986	396,267
1928	4,371,924	7,305,277	1,952,654	977,468	387,879
1929	4,784,009 "	7,302,063	2,063,229	1,028,791	388,711
1930	3.654,075	5,502,129	1,514,263	840,409	296,990
1931	2,628,358	3,917,997	957,740	499,899	158,213
1932	1.603,892	2,260,689	680,520	248,378	111,048
1933	2,256,028	3,106,095	784,626	316,471	125,126
1934	2.379,642	3.064,270	1,014,447	457,089	171,841
1935	3,145,237	3,452,527	1.355,713	609,212	233,633
1936	4,077,424	4,572,397	1,647,537	723,804	295,233
1937	4.351.723	4,712.698	1.775,734	797.492	335,045
1938	3,790,896	3.348.567	1,461.964	570,571	221,579
1939	4,764,804	4,244,001	1,684.644	675.165	271,096
1940	5,202,111	4.541,702	1,954,500	773,650	325,338
1941	6,346,470	5,239,713	2,331,893	912,203	373.970
1942	6,480,178	4,976.170	2,330,041	930,368	433,089
1943	6,401.424	4,490,086	2,352.592	889.748	423,520
1944	6,322,259	4,349,914	2,468.943	910.545	448,498
1945	5,003,547	3,257,995	2,260,792	780,453	341.749
1946	6,328,317	3,422,289	2,681,173	863,964	413,859

*GPO 596 - 80S (198S)

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