Chapter 9

Water Transportation and Storage of Logs

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Transportation is one of the major problems facing the entrepreneur in the lumber industry. Bryant (1913) hypothesized that the "transportation of forest products to mill or market represents 75% 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 from 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 the 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 effects of water transportation of logs in western North America can be divided into those caused by the historical driving of logs in rivers and streams and those due to the current dumping, rafting, and storage of logs in rivers and estuaries. The historical perspective focuses on habitat losses and the volumes of logs transported by water, both fresh water and marine. Many changes in stream-channel structure and evidence of habitat simplification still exist today, nearly 100 years after river-driving activities have ceased. The current perspectives on British Columbia and southeastern Alaska, as well as on a few locations in Oregon and Washington, draw extensively on excellent summaries, reviews, and task-force reports from both Canada (Duval et al. 1980) and the USA (Hansen et al. 1971).

The objectives of this chapter are to review and describe historical log transportation in rivers, which was extensive in the western USA and eastern British Columbia; to provide perspectives on the volume of logs transported and areal extent of the estuarine and river habitats allocated to log transfer and storage; and to describe the environmental effects of log transfer and storage that relate to fish habitats.

Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats
American Fisheries Society Special Publication 19:325-368. 1991

Historical Log Transportation

Numerous books have described the history of the timber industry, and many articles have glorified log drives on rivers. However, one book (Rector 1953) stands out for its descriptions of the role that water transportation played in the early days of the timber industry. Extensive reports produced from research undertaken for the State Lands Division of Oregon document the extent of navigation for each of Oregon's major river basins (J. E. Farnell, Oregon Division of State Lands, Salem, personal communication). Each of 23 basin studies was issued as a navigability report that records the extent, duration, and dependence on water of log transportation.

The first sawmills on the west coast of North America, established 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 1880s, the best timber within 3.2 km of the entire shoreline of Hood Canal, Washington, 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. In 1883, a newspaper *(The West Shore)* announced 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 1880s the same was true of almost any county along the lower Columbia River, around Puget Sound, or along the "lumber coast" (Cox 1974). The centers of the timber industry reflected this dependence on water (Figure 9.1).

Historically, the lumber industry in the northwestern USA 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 lumber centers had disappeared by the turn of the century. The big lumber centers today are still usually located where they can service markets by both rail and sea.

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 Michigan, Wisconsin, and Minnesota, the courts decided that a stream that could float a saw log was a "public highway" and that 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 U.S. 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 follows:

> 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

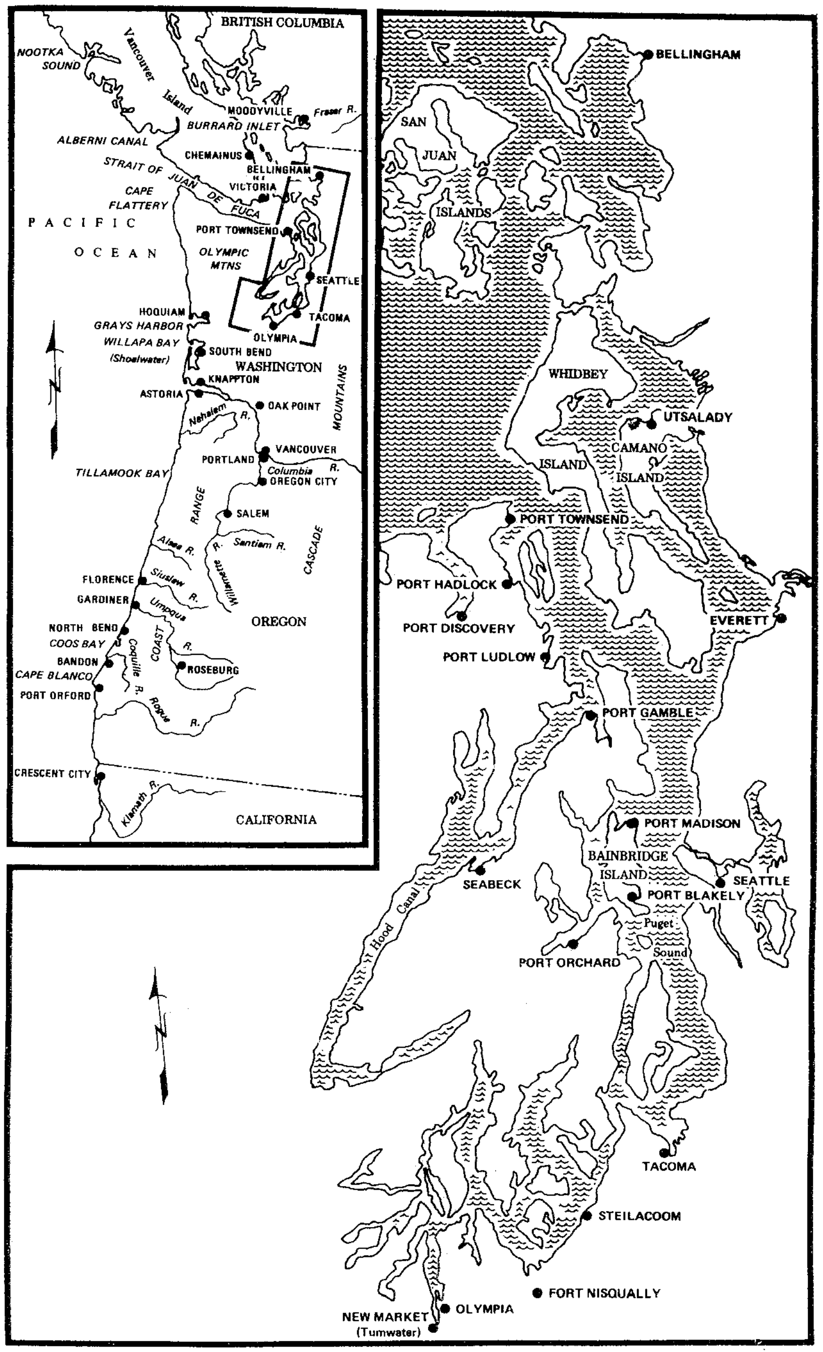


FIGURE 9.1.-Lumber centers of the Pacific Northwest before 1900. The Puget Sound area, boxed in the small-scale map, also is shown at an expanded scale. (From Cox 1974.)

> 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, the state owned the streambed. If the stream was floatable but not navigable in the usual commercial sense, 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 U.S. 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 quasipublic 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 Modifications

Log driving is the process of transporting logs by floating them in loose aggregations in water; the motive power is 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 to 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 alterations, canals, tramways, trestles, log chutes and slides, trucks, and railroads for log transport, 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. It was built of log cribbing and sometimes was many meters in height and width. When it accumulated a large head of water, the water was released. Logs that had been dumped into the pond behind the dam, together with others collected along the watercourse below the dam, were quickly sluiced downstream to where they could be handled by conventional means.

Streams of all sizes had to be “improved” before a log drive could begin. Two principal forms of stream improvement were used (Brown 1936). (1) Sloughs, swamps, low meadows, and banks along wider parts of the streams were blocked off with log cribbing to keep the logs and water in the main stream channel. (2) Boulders, large rocks, leaning trees, sunken logs, or obstructions of any kind in the main bed during periods of low flow were blasted out or otherwise removed. Obstructions or accumulations of debris, such as floating trees, brush, and rocks, often caused serious and expensive log jams during the driving seasons. Small, low-gradient streams often were substantially widened during log driving by frequent flushings of the stream from splash dams and by the impacts of logs along the streambank. Excellent historical accounts of activities to clear river obstructions and methods of stream improvement were provided through interviews with pioneers, county and state court records, and reports of the U.S. Army Corps of Engineers (e.g., 1937).

By 1900, over 130 incorporated river and stream-improvement companies were operating in Washington. Use of major splash dams in western Washington and western Oregon was common practice and very extensive. Over 150 major dams existed in coastal Washington rivers, and over 160 splash dams were used on coastal streams and Columbia River tributaries in Oregon. On many smaller tributaries, temporary dams were used seasonally, but no records of these were kept. Many of these dams formed barriers to fish migration (Wendler and Deschamps 1955), but the long-term damage to fish habitats was probably caused by stream alterations made before drives and the scouring, channel widening, and displacement of main-channel gravels that occurred during the drive.

Small streams were seriously affected by logging of western redcedar, which occurred many years before clear-cut harvest. Because redcedar was used for shingles and not just for lumber like Douglas-fir, it could be cut up into small bolts (<1-m lengths) and 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, and 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 to 1978. During this period, about 3,000 snags per year were removed from 322 km of the Skagit, Nooksack, Snohomish, Stillaguamish, and Duwamish rivers. In 1890, Coquille County, Oregon, authorized a public snagging operation on the Coquille River system that continued until the early 1970s.

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 et al. 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 River, Washington, in the mid-1880s, the resulting flush of channel sediments filled more than a kilometer's stretch of Bellingham Bay (U.S. Congress 1892). Sediments released during cleanup activities and transported by the Siletz River filled Siletz Bay between 1905 and 1923 (Rea 1975). River snagging caused sediments to be displaced from main channels and deposited in the bays below. All coastal Oregon and Washington rivers reflect alterations resulting from "improvements" required 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. Millions of cubic meters 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 (Timberman 1941). Many of the mining and smelting activities in Arizona, Montana, Utah, and Colorado in the late 1880s 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 railways and driving the logs down streams that intersected the line (Brown 1936).

The rivers in the more arid parts of the USA also had to be improved before log drives could begin. Marble Creek on the St. Joe 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 1,180 m^3 (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 described the fishing in these creeks as exceptional, but noted that the once-numerous larger fish were no longer present 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 Tenana rivers and their tributaries have been well documented; in particular, they supplied timber during the gold rush in the early 1900s. Tributaries of the Fraser River, British Columbia, 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 altered in one way or another. Blasting boulders and pulling debris and snags was usually all that was required on the larger streams. Throughout western North America, 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, "river improvement" attitudes from the log-driving days have been common in fisheries management until recently. Debris-jam removal and snagging for navigation and fisheries reasons have resulted in the long-term loss of fish habitat along thousands of kilometers of streams in the western USA (Sedell et al. 1982; Sedell and Luchessa 1982). Salvage logging and snagging at the lower ends of rivers in Oregon, Washington, and Alaska continue on a large scale today. The salvage results in loss of habitat complexity essential for both spawning and rearing of salmonids. Many philosophies carried over from the log transportation and navigation days need to be overcome if we are to have an effective plan for protecting salmonid habitats.

Historical Review of Effects of Log Handling on Salmonid Populations

Scouring and Flow Manipulations

During early development of logging along the Pacific coast of the USA, log driving in many streams that had 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 from the scouring and silting associated with water releases and from the dewatering that occurred when the splash dams were closed. In addition, rearing areas for 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) 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 initial 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 10 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 in 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 et al. 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 salmon. The operation of this dam was of great concern to the local fishery manager, who tried (unsuccessfully) to avoid the adverse effects of sudden releases of water (Shotton 1926). Thompson (1945) concluded that manipulation of river flow by the dam had adversely affected the Adams River sockeye salmon run and most likely had caused the decline in this run that was observed after 1913, though the damage caused by water surges could not be distinguished from that caused by log gouging. Subsequent increases in the sockeye salmon population were attributed to the return to more normal flow conditions in 1922. The dam ceased to be used in the late 1920s and was removed by the International Pacific Salmon Fisheries Commission in 1945. In their survey of the Lower Adams River in 1940, however, Bell and Jackson (1941) noted extensive and persistent alterations of the stream that had resulted from splashing; the stream was recovering only slowly.

Most 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).

In its 1955 brief to the Sloan Commission on Forestry, the Canada Department of Fisheries (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 flow 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 et al. 1959).

The modern method of transporting logs from the forests to mills or shipping points is by trucks that use 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 by salmonids for spawning. The Clearwater River in Idaho was used for log driving until the late 1960s, but little spawning by steelhead and spring chinook salmon takes place in affected parts of the river.

Bark Losses and Deposits

Much of the bark on logs is knocked off during a drive by contact with the streambed or bank and 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% of the bark was removed during pulpwood drives in Quebec, and several tonnes 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 that 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 was more securely attached to these winter-cut trees than to trees cut in summer, it became waterlogged and 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 Modifications

Rarely can logs be driven down a river that is not "improved" in some way to prevent permanent stranding or jamming at difficult spots. 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 logjams, 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 the 1860s to the 1920s. In Washington, over 300 river- and stream-improvement companies were registered from 1898 to 1948, over 75% of them 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. This not only destroyed spawning grounds along 200-300 m of river below the diversion, it changed the hydraulic structure and reduced the amount of suitable spawning ground for about 500 m upstream from the new channel. The new channel was never productive of fish (International Pacific Salmon Fisheries Commission 1966).

The Canada Department of Fisheries (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 log driving on this river (now discontinued), 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. The salvage of stranded logs is an inevitable feature of river log driving. Salvage may require river boats and personnel, dynamite to break up jams, or bulldozers to push logs back into the river. Such operations break down the river banks, gouge the stream bed, and otherwise disturb (often lethally) fish and their eggs.

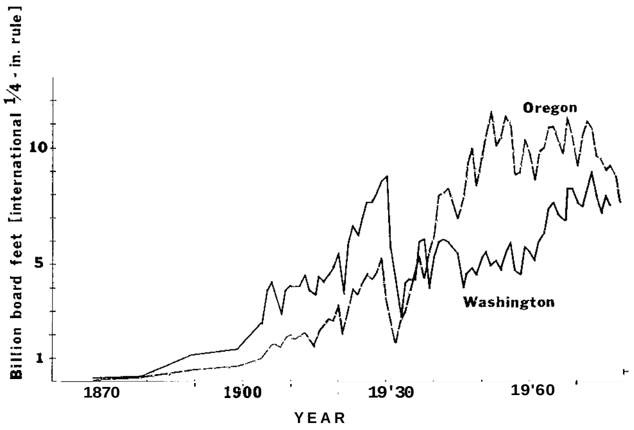


FIGURE 9.2.-Lumber production in Oregon and Washington, 1869-1980.

Intensity of Log Rafting and Forest Operations: Regional Differences

The history of development of the timber industry in western North America reflects geographical patterns. Shipping and cargo mills led to the development and persistence of processing centers located to accommodate 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 effect of log transportation 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, and flood and debris control, as well as because of current management guidelines for fish habitats.

New laws and better enforcement of them have considerably reduced the degradation of water quality. Economic factors have played a large part by forcing the continual closing and consolidation of wood-processing facilities. McHugh et al. (1964) reported that Oregon had about 4,860 hectares of log ponds and 800 hectares of sloughs or canals used as log-storage sites in the early 1960s, Washington had about 1,620 hectares of log ponds and 600 hectares of storage sloughs, northern California had about 1,620 hectares of such storage areas, and Idaho had 400 hectares. The size of the ponds varied from less than 1 to over 160 hectares in surface area and from 1 to 9 m in depth. These figures are probably half as large now because of mill closures and dry-land sorting and processing. Figure 9.2 illustrates lumber production during the last century for Oregon and Washington, the major timber-producing states in the western USA. The use of water for log storage and transportation in the western USA reflects the same trends that were seen in Washington during its peak transfer production in the late 1920s.

Historical Intensity of Log Rafting in Western North America

Oregon.—Oregon's major rivers, the Columbia and Willamette, and its estuaries have been used intensively from the beginning of timber production to the present for log handling and transportation. Marriage (1958, J. W. Johnson (1972), Oregon Division of State Lands (1973), and Percy et al. (1974) provided excellent summaries of key characteristics of Oregon estuaries derived from detailed map analyses and surveys and from zoning and state land-use records. Percy et al. (1974) identified and tabulated 21 Oregon estuarine areas ranging from about 53 to 3,800 hectares in surface area (to the inland extent of tidal action) and draining areas of between 35 and 13,000 km^2.

Log-processing and -shipping centers in Oregon are located in nine major areas where aquatic environments are affected: 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. Of the current 16.5 million m^3 (7 billion board feet) of timber annually transported to mills, 25% are towed in these areas. Log-transport activity throughout the state has fluctuated over the years, sometimes substantially, in response to many events that influenced timber production, including forest fires, timber demand, mill openings and closures, changes in timber management strategies, environmental regulation, construction and housing starts, and relocation of major lumber centers. Different areas, however, experienced different periods of peak activity according to the factors influencing timber production at that time. The Columbia and Willamette river basins have supported log traffic from before 1890 and experienced peaks during World War II, but timber transport in the other major river basins did not reach heights of activity until the late 1950s and early 1960s. The mid to late 1970s saw a significant increase in logging activity in most major coastal waterways as a result of a national housing boom.

During World War II, over 2.3 million m3 (1 billion board feet) of timber were transported annually from the Willamette basin down the Willamette River, through the Oregon City Locks, to Portland and Columbia River sawmills. This activity ceased, however, 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 et al. (1982) identified 96 coastal and inland estuaries in 14 regions of the state. Estuaries within these regions are structurally, hydrologically, and biologically diverse, and range downward in size from drowned river valleys, which form the major estuaries (for example, Grays Harbor and Skagit Bay–Port Susan), to the numerous small stream-channel estuaries characteristic of Puget Sound and the Strait of Juan de Fuca, as well as southeastern Alaska and much 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. The natural estuarine environments have been affected both directly and indirectly, the latter via log drives, urbanization, and diking in their 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 by Simenstad et al. 1982). Although changes in most west coast estuaries have not been quantified, Bortleson et al. (1980) reported changes in 11 major estuaries of Puget Sound. Such estuaries as the Duwamish and Puyallup 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 have 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 (Dorcey et al. 1978; Simenstad et al. 1982).

Washington's primary timber transport waterways include the Cowlitz, Lewis, and Chehalis rivers and Tacoma and Grays harbors. These areas closely reflect periods of timber activity for the entire state, and have themselves been responsible for the transport and storage of 2.3-5.9 million m^3 (1–2.5 billion board feet) annually during several periods over the years. As with Oregon, Washington's peak periods of timber transport activity corresponded to the many factors influencing timber production cycles, including diminishing old-growth stands and the initiation of second-growth harvesting. Peaks in river–harbor transport activity depended on the particular system and associated factors that influenced regional timber production; overall, however, peaks in timber transport activity occurred after 1910 and into the mid-1930s, during the late 1940s to early 1950s, in the early to mid-l960s, and again during the mid-1970s.

In the early days, 100% of the logs were transported by water. Grogan (1924) estimated that 60% 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 (representing about 12 million m^3 or 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 30 million m^3 (12 billion board feet) annually (Edgell et al. 1983). The most economical means of transporting logs from the forests to the mills is by marine waterways, large interior lakes, and the Fraser River system. Cottel(1977), Boyd (1979), and Edgell et al. (1983) estimated that about 90% of the coastal timber harvest is placed in the water during part of its transportation to processing areas. Boyd (1979) documented regional differences in production, species harvested, and modes of log transport within the coastal British Columbia forest industry during 1978.

Alaska.—Alaska totally depends on water to move logs to four major processing centers: Wrangell, Petersburg, Sitka, and Ketchikan. The number of estuaries counted in Alaska has ranged between 1,000 and 22,000, depending on how "estuary" is defined; the large glacial bays (fjords), each with numerous tributaries, and the many large and small islands make the delimitation of estuaries quite arbitrary (Faris and Vaughan 1985). In any case, Alaska's total estuarine area exceeds even that of British Columbia. Almost 650,000 km^2 of estuarine area, 47%

of which is less than 18 m deep, abut the Tongass National Forest (Faris and Vaughan 1985).

Alaska was a relatively late starter as a timber producer; the primary mills in Ketchikan and Sitka opened in the mid to late 1950s. Both production and log transport activity are less than in several other timber-producing jurisdictions in northwestern North America. The mills of Ketchikan and Sitka collectively handle 700,000 to more than 1.1 million m3 (300–500 million board feet) of timber per year; Ketchikan receives more than 60% of this total. The largest harvests so far occurred in the mid 1960s to mid 1970s. The total Alaska timber harvest peaked at more than 1.3 million m^3 (570 million board feet) in 1970 and probably will not exceed 1.7–2.1 million m^3 (750–900 million board feet) per year during the best of times.

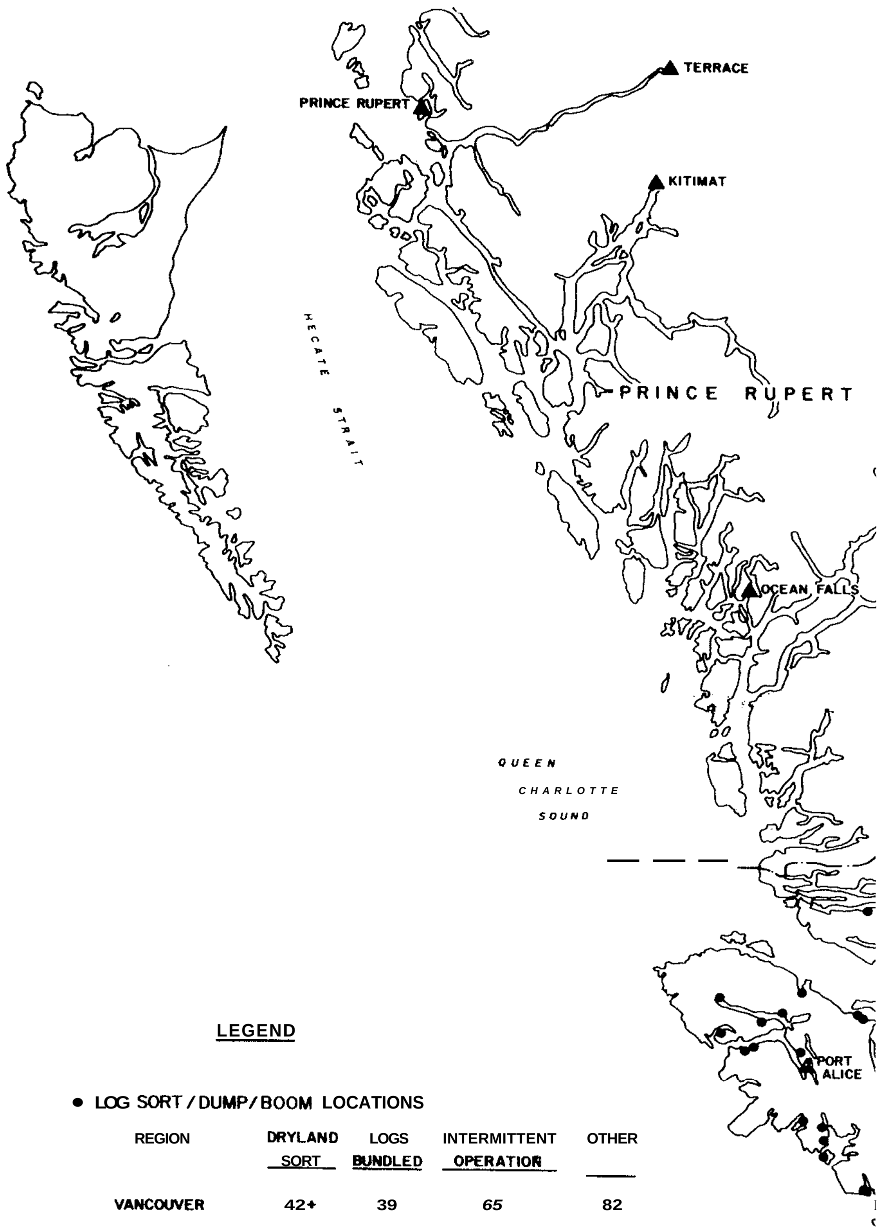
Idaho and Montana.—Large numbers of logs have been and continue to be rafted down the St. Joe River to Coeur d'Alene Lake, Idaho, then across the lake and down the Spokane River into Washington. Log volumes peaked in the 1920s and since then have been sustained at an annual rafted volume of about 236,000 m^3 (about 100 million board feet). Lakes and rivers that received the transported logs in the past are Flathead Lake in Montana, and Coeur d'Alene Lake, St. Joe River, Pend Oreille River between Priest River and Ione, and Priest River in Idaho. Peak activity for all but Flathead Lake was in the 1920s. Flathead Lake mills served the mines and railroads from 1905 to 1920.

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 cubic meters 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 millions of cubic meters of logs shipped from Oregon and Washington. Humboldt Bay was too shallow to maintain a great volume of log rafts in its waters, although some logs still are rafted near the mills

TABLE 9.1.—Location and average size of coastal British Columbia log-handling leases.[a] (From FERIC 1980.)

Location	Area (hectares)	Portion of total leases (percent)	Average area (hectares)
Lake[b]	197.8	2.2	12.4
River[c]	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	0.5	12.2
Total	8,956.2	100.0	

[a]Based on a questionnaire survey of 187 companies with 943 leases; the response rate by the British Columbia coastal forest industry was 66%.
[b]Pitt and Harrison lakes.
[c]Fraser River constitutes 98% 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 & PAPER 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 9.3.—Modern locations of log sorting, dumping, booming, and processing along the south coast of British Columbia. (From Ainscough 1979.)

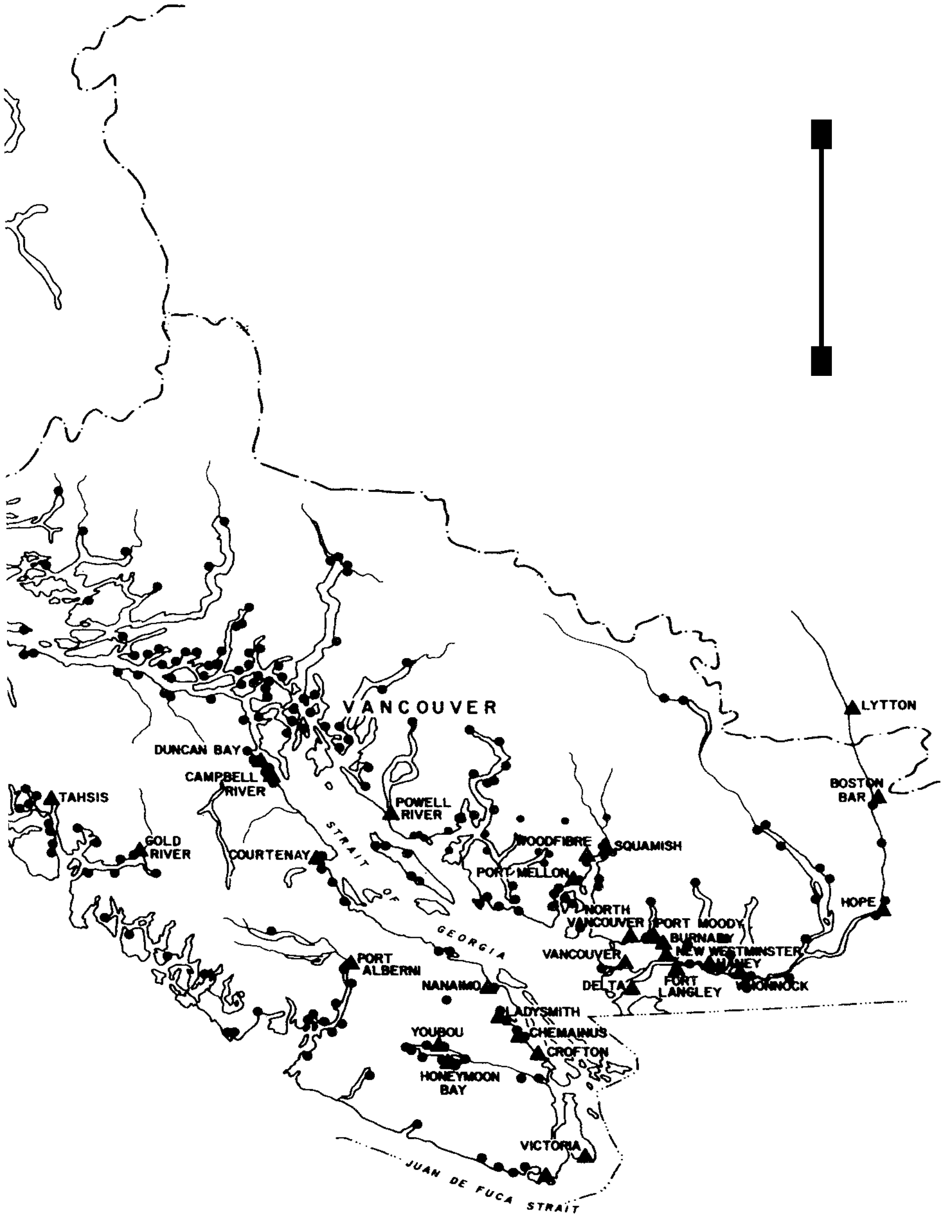


Figure 9.3.—Extended.

TABLE 9.2.-Major uses of coastal British Columbia log-handling leases.[a] (From FERIC 1980.)

Use	Area (hectares)	Portion of area (percent)
Log dumping	204.2	2.3
Barge dumping	132.6	1.5
Barge loading	205.6	2.3
Log sorting and booming	1,312.0	14.6
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

[a]Based on a questionnaire survey of 187 companies with 943 leases (66% response).

there. Most of California's bays are not located in timber country or are too small and rocky to handle much log transportation.

Extent of Leased Log-Storage Acreages

Leased log-storage acreages in Oregon total 794 hectares. Of these, 41% are in coastal estuaries and most of the rest are along the Columbia and Willamette rivers. In Washington, 943 hectares are leased for log handling, of which 85% are in estuaries.

In 1981, British Columbia had 950 coastal lease areas and reserves occupying about 11,000 hectares (Wilson 1981, cited in Edgell et al. 1983). A survey by FERIC (1980) the previous year indicated a slightly smaller total lease area; the majority of sites were in coastal rivers, intertidal areas, and deep-water environments. Log-handling sites in estuaries tend to be larger than other leased areas because most log-processing sites are located there (Table 9.1). Ainscough (1979) documented the locations of major log-sorting, -dumping, -booming, and -processing sites along the south coast of British Columbia (Figure 9.3).

The FERIC survey indicated that the greatest proportion of log-handling water leases in coastal British Columbia were used for log storage; relatively minor areas were used for dumping and, to a lesser extent, sorting (Table 9.2). This information has been considered representative of present Canadian coastal practices. In a comprehensive report of British Columbia log-handling practices and coastal zone management, Edgell et al. (1983) showed that 64% of coastal water lease areas were reserved for log storage. They also found that of 27,000 km of British Columbia coastline (including 950 km north of the 49th parallel), only a very small proportion could feasibly be used for log-handling operations; of those areas leased, 47% were shallow intertidal areas, estuaries, and bays. Along its inside waters, 33–57% of British Columbia's log-handling lease areas are centered in estuaries. Edgell et al. (1983) noted the ever-increasing demand for suitable log storage areas, projected to increase 20% by the year 2000, which will compound current shortage problems. Of further significance, southern Vancouver Island and the lower British Coiumbia mainland, which combined produce only 22% of the coastal timber harvest, handle more than 70% of coastal timber processing (Boyd 1979).

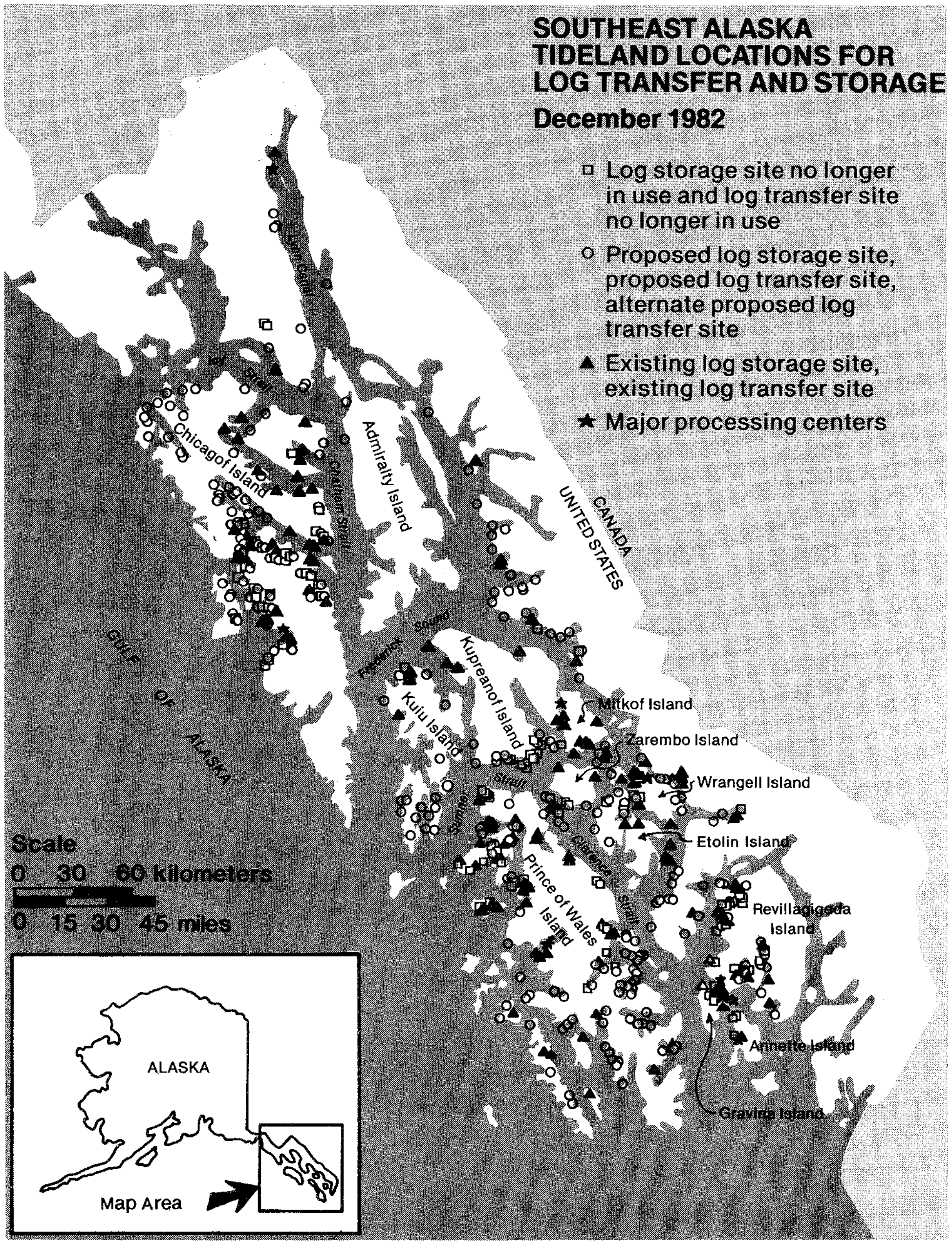


FIGURE 9.4.—Tideland locations for log transfer and storage in southeastern Alaska, 1982. (From Faris and Vaughan 1985.)

Alaska has 430 hectares 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). Faris and Vaughn (1985) mapped processing plants; abandoned, new, and proposed dump sites; and abandoned, currently occupied, and proposed storage sites (Figure 9.4). They

TABLE 9.3.—Comparison by state and province of log-handling leases, area affected, and board feet of logs transported.

State or province	Number of sites leased	Number of hectares leased	Estimated board feet of logs transported or stored (millions)
Southeastern Alaska	81	430	400
British Columbia	943	8,956	6,030
Washington	154	943	4,000
Oregon	I00	794	3,500

estimated that 0.01% of the total estuarine area was affected by bark accumulation adjacent to the log-transfer facilities and projected that a worst case for the future would represent 0.04% of the estuarine total. Volumes of logs are not great in Alaska when compared with log-handling activity in British Columbia, Washington, and Oregon (Table 9.3).

When the activity per hectare leased is compared to total estuary available, log handling, although occupying sensitive intertidal zones, impinges on less than 0.001% of the estuary area available. Guidelines are in effect to minimize the effects by limiting site location. Log transportation directly affects estuaries in British Columbia much more than in Alaska, Washington, and Oregon (Table 9.3). British Columbia has also spent more money and time analyzing and researching the problem than has any other jurisdiction.

Major Phases of Coastal Log Handling: British Columbia and Southeast 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 timber sales, winter log-raft storage areas, and storage and sorting areas near the mills.

The major phases of log handling were reviewed in detail by Boyd (1979), Duval et al. (1980), and FERIC (1980) for British Columbia and by Beil(l974) 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 rafts to storage areas or transported on barges to dumping sites. At sites of barge dumps 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 the four major log-handling processes: dumping, booming, storage, and transport.

Dumping.—Dumping is the process of introducing cut timber into the water for sorting, booming, and transport. Dumping is generally done at a landing constructed along a watered bank at a site adjacent to major harvest areas, but it also is done from previously loaded barges on the water. Methods of dumping include use of stationary vertical-hoist systems such as A-frames, ginpoles, and parbuckles; cranes; mobile equipment such as Caterpillar tractors, skidders, and front-end loaders; slide ramps; cable carriages; and self-tipping barges.

Booming.—Historically, many kinds of rafts and booms have been used. The two basic types currently used are flat rafts and bundle booms. Flat rafts consist of logs stored and towed loose inside a series of channel boomsticks. These rafts cover about 0.4 hectare. In Canada, the rafts are divided into sections of about 21 × 21 m; each section holds 35-238 m^3 (15-101 thousand board feet). Rafts of up to 30 sections are common. Bundle booms comprise logs that are bundled loosely with wire or metal bands. Bundles range from 7 to 106 m^3 (3-45 thousand board feet) and usually draw 1.5-2.5 m of water. The bundles are stored and rafted like the flat rafts. A raft of bundles contains a log volume of 707-1,416 m^3 (300 to 600 thousand board feet). Fewer logs are lost from bundles than from flat rafts, and bundles make the sorting process more economical and efficient.

Storage.—Marine storage of logs can occur in intertidal, shallow, or deep water. Logs are often stored near freshwater inflows to reduce infestations of the marine molluskan shipworms Teredo navalis and Bankia setacea, although the degree of protection this technique affords depends on salinity, currents, storage time, and season. The most efficient means of reducing shipworm damage is to keep storage times short. Storage areas differ in size. Larger areas generally are needed if logs have to be stored for extended periods; conversely, proximity to harvest sites may dictate use of small areas. Average storage leases in British Columbia range from 200 to 400 hectares (Edge11 et al. 1983).

Transport.—Logs are moved directly on the water as flat rafts, from which log loss is high and which are limited to calm inside waters, and as bundles, which retain logs better than flat rafts and which are 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 only a 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 79,830 kg each have been developed and should reduce the 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 et al. (1980) summarized the typical locations and required conditions for each phase of log handling. These conditions are indicated in Table 9.4.

Effects of Log Handling on Estuarine Biotic Communities

The interaction of forestry practices and fishery resources has generated increasing discussion and debate since the early 1970s. Much of the discussion has centered on lotic freshwater systems and their responses to timber harvest strategies, but concern also has grown over the highly sensitive and productive estuarine environments that are used extensively for handling and storing of logs. As a result of intensified research efforts over the years, forest management guidelines and regulations that help protect the environmental integrity of

TABLE 9.4.-Typical conditions for log handling on British Columbia coastal waters and adjacent land.

	Minimum depth of water (m)			Estuaries		
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)
Skidding (not common)						
Skidding onto beach	X				X	
Yarding into water						X
Tractor pushing					X	
Dumping						
Lift and lower bundles	X	X		X		X
Lift and lower loose logs		X		X		X
Parbuckle onto log, skids bundles		X		X	X	X
Parbuckle onto log, skids loose logs	X	X		X	X	X
Mobile loader over skids bundles		X			X	X
Mobile loader on gravel ramp, loose logs	X	X			X	
Helicopter drop			X			X
Sorting in water						
Loose logs		X			X	
Loose logs to make bundles		X			X	
Bundles			X		X	
Booming						
Bundle booms		X				
Flat rafts		X				
Bag booms		X				
Storage						
Bundle booms		X				
Flat rafts	X	X				
Bag booms	X	X				
Dry-land sort					X	
Barge loading and dumping						
Loose logs					X	
Bundles					X	
Transporting						
Bag booms	X	X		X	X	X
Flat booms	X	X		X	X	X
Bundle booms		X		X	X	X
Barges					X	X
Retrieval						
Flat raft		X			X	X
Bundle boom		X		X	X	X

freshwater stream systems are now in place. Management policies are still being formulated for the estuarine environment. Estuaries provide unique environments at the junctions of fresh and salt water, and support numerous forms of life. Estuaries are very important for salmonids and other anadromous fishes; adults use them as staging areas for upstream spawning migrations and juveniles and smolts use them as rearing areas. Because estuaries are so essential to these and many other species, the effects of particular estuarine disturbances on species and

TABLE 9.4.--Extended.

Log-handling phase	Bays and sheltered reaches: Tidal marshes, muddy shore, 10% slope	Bays and sheltered reaches: Gravel shore, 10-40% slope	Bays and sheltered reaches: Rocky shore, 40-60% slope (deep water)	Exposed shoreline: Gravel, 10-20% slope	Exposed shoreline: Rocky, 20–50% slope (deep water)
Skidding (not common)					
Skidding onto beach		X		X	
Yarding into water			X		
Tractor pushing		X		X	X
Dumping					
Lift and lower bundles		X			
Lift and lower loose logs		X			
Parbuckle onto log, skids bundles	X	X	X		
Parbuckle onto log, skids loose logs	X	X	X		
Mobile loader over skids bundles	X	X	X	X	X
Mobile loader on gravel ramp, loose logs		X		X	
Helicopter drop			X		X
Sorting in water					
Loose logs	X	X			
Loose logs to make bundles		X			
Bundles					
Booming					
Bundle booms	X	X			
Flat rafts	X	X			
Bag booms	X	X			
Storage					
Bundle booms	X	X			
Flat rafts	X	X			
Bag booms	X	X			
Dry-land sort		X			
Barge loading and dumping					
Loose logs		X			
Bundles		X			
Transporting					
Bag booms	X	X	X		
Flat booms	X	X	X		
Bundle booms		X	X		X
Barges		X	X	X	
Retrieval					
Flat raft	X	X	X		
Bundle boom		X	X		

communities must be better understood. Log handling and storage cause both physical and chemical disturbances. Most foreshore areas are leased for log-handling operations because these operations require sheltered areas as well as proximity to mill centers and adequate inflows of fresh water for discouraging wood-boring shipworms (Edge11 et al. 1983). Consequently, log handling is generally sited in biologically sensitive environments.

As summarized earlier in this chapter, water transportation and storage of logs have been practiced for more than 100 years in western North America, and many north Pacific estuaries are still used for these purposes today. Thus, one must take into account the duration of timber-related disturbances and consider their possible cumulative effects. We point out, however, that large woody debris is an important ecological feature of freshwater and estuarine systems even in the absence of logging, so the effects of current log-handling activities are not necessarily all negative.

The transportation and storage of logs along aquatic systems generates, as previously noted, two distinct modes of disturbance: physical and chemical. Both modes create direct as well as indirect effects on fish habitat and abundance, and these various influences may interact to produce synergistic effects. These processes and their outcomes must be viewed independently as mitigating management strategies are developed.

The spatial extents and degrees of log-handling impact are directly related to the flushing characteristics of waters near handling sites, the methods of handling logs, and the intensity of use in each area. With these general principles in mind, we next consider the specific effects that log-handling operations have on aquatic systems. Tables 9.5–9.7 summarize our discussion. We hope these tables also will serve as a management tool to identify causes and effects and to guide research and mitigation efforts.

Physical Disturbances

Physical disturbances resulting from log-handling operations (dumping, sorting, storage, and transport) include substrate disturbances in areas where logs contact the bottom or log-moving machinery is used in shallow areas; deposition and subsequent dispersion of whole logs, bark, wood debris, and other debris (for example, bundling bands) associated with log handling; disruption of the water column; and reductions in wave action and light penetration. The magnitude and spatial extent of these disturbances differ among types and volumes of log-handling activity, water depths, site morphologies and substrates, species and ages of logs handled, seasons, and prevailing currents and circulation patterns. Because log sorting, booming, and storage frequently occur in conjunction with dumping, it may be difficult to distinguish the separate effects of these activities. Quantitative information about these physical disturbances is limited and primarily addresses log-storage operations.

Biotic communities are affected by 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 physical disturbances of the water column (Conlan 1975; Bell and Kallman 1976b). Although several authors have discussed the effects of various phases of log handling on plants, no quantitative data and only a limited amount of observational information are available describing these effects. Despite this shortage of published information, damage to emergent vegetation in particular is clearly evident in many coastal areas used for log handling (Duval et al. 1980). Studies relating the effects of log handling to benthic invertebrates in coastal environments have 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

TABLE 9.5.—Summary of log-handling effects on aquatic plant communities.

	Effect			
Evaluation	Compaction or scouring of soft substrates	Scouring or abrasion of hard substrates	Accumulation of wood and bark debris	Changes in light quality and intensity
Major source of effect	Log dumping in shallow areas and intertidal log storage; propeller wash in shallow areas	Log dumping in shallow areas; stranding of lost logs in intertidal environments	Log dumping and sorting; minimal contribution by log storage	Log dumping related to increases in water turbidity; shading by rafted logs; presence of highly colored leachates
Positive effects and modes of action	None	None	Increased habitat for some rnacrophytes in areas with scattered debris; use of dissolved organic compounds in leachates by heterotrophic forms. Direct and indirect action	None
Negative effects and modes of action	Physical damage and uprooting of eelgrass and emergent vegetation; potential decreased primary production by benthic microalgae. Direct action	Physical damage to intertidal algae. Direct action	Decreased species diversity and abundance of benthic microalgae and macrophytes. Direct action.	Decreased primary production by autotrophic species; potential changes in species composition in benthic forms under rafted logs. Indirect action.
Degree of effect	Insignificant to minor	Insignificant	Insignificant to moderate	Insignificant to minor
Factors influencing degree of effect	Presence of extensive eelgrass meadows would increase potential for effects; intertidal log storage in estuaries would also increase effects	Increased effects from intertidal log storage; reduced algal and epibenthic invertebrate forms	Effect assessment hampered by data deficiencies; effects would be greatest in estuarine areas where plant communities provide habitat and food for invertebrates, fish, and birds	Shading by extensive log storage in estuaries would increase potential for light-related effects; also depends on time of year

1977; Zegers 1978); reviews of available literature describing effects of log handling on invertebrates were provided by Conlan (1975, 1977), Hansen et al. (1971), and Smith (1977).

Substrate disturbances.—Substrate disturbances may occur during log dumping, sorting, storage, and transport, though generally only when these activities occur in shallow intertidal waters. The effects of sediment scouring and compaction at dumps have not been documented because at shallow sites where such

TABLE 9.6.--Summary of log-handling effects on benthic and intertidal invertebrates.

	Effect			
Evaluation	Bottom scouring	Sediment compaction	Accumulation of wood and bark debris; lowered oxygen levels; toxic accumulations of H_2S and log leachates	Physical changes in sediment and bottom composition
Major source of effect	Free-fall dumping in shallow waters (including barge dumping); tug wash in shallow estuaries	Free-fall dumping in shallow waters and intertidal log storage	Free-fall dumping; water sorting; log storage is generally a minor contributor	Free-fall dumping and water sorting; flat-rafting may contribute to log sinkers
Positive effects and modes of action	None	Possible increase in abundance of some species of mobile epifauna such as harpacticoids. Indirect action	None	Increased abundance of epifauna where scattered bark and debris provide additional habitat and attachment sites (woodboring species, amphipods, shrimp, prawns, crabs, tunicates, nonburrowing anemones). Indirect action
Negative effects and modes of action	Crushing of epifaunal and infaunal species; habitat disturbance. Direct action	Destruction of habitat and crushing of suspension-feeding fauna (bivalves, polychaetes); decrease of infauna and sedentary species of epifauna. Direct and indirect action	Mortality of epifauna and infauna; potential sublethal effects resulting in altered secondary production. Direct action	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 action
Degree of effect	Insignificant to minor	Insignificant to moderate (moderate when site used 10 years)	Insignificant to moderate	Minor to moderate
Factors influencing degree of effect	Dumping or other activities causing scouring in important areas, such as estuaries or commercial and recreational shellfish-harvesting areas, would lead to minor effect	Large storage areas in important estuaries or commercial and recreational shellfish-harvesting areas; duration of use of log-handling area	Few reported instances; lack of information for benthic environments; dumping and sorting in important estuaries or commercial and recreational shellfish-harvesting areas may increase effects	Extent of debris coverage; importance of area; important estuary or commercial and recreational shellfish-harvesting area

TABLE 9.7.--Summary of log-handling effects on fish.

Evaluation	Effect: Bottom compaction and scouring	Effect: Accumulation of wood and bark debris and floating material	Effect: Physical disturbance to water column and bottom
Major source of effect	Free-fall dumping; water sorting; intertidal log storage	Log storage and bark and wood debris accumulations at dump and water-sorting areas	Free-fall dumping; water-sorting in shallows; intertidal log storage
Positive effects and modes of action	None	Increased abundance of some fish-food organisms; possible attraction of some species to log raft or debris habitats. Indirect action	None
Negative effects and modes of action	Loss of aquatic plants for Pacific herring spawning; loss of invertebrate food organisms. Indirect action	Toxicity of sublethal effects from log leachates and low dissolved oxygen; loss of fish-food organisms in areas of heavy debris accumulation. Direct action	Disturbance to fish present; destruction of Pacific herring and smelt spawning. Direct action
Degree of effect	Insignificant to moderate (potential)	Insignificant	Insignificant to minor
Factors influencing degree of effect	Importance of spawning area and areal extent of disturbance determine site-specific effect (no documentation of effects on fish populations)	Toxicity-related effects may increase with decrease in salinity and decrease in degree of tidal flushing (no documented instance of toxicity to fish in the field)	Fish use depends on time of year and is restricted to some areas (no documented evidence of effect)

disturbances are likely, large accumulations of bark and wood debris simultaneously distort the bottom ecology. Parbuckle dumps and any form of skidding are likely to cause the greatest amount of scour and compaction, "lift and lower" and helicopter dumps the least. Because terrestrial log dumps remain in a single location while logging goes on in a particular area, substrate disturbances are likely to be localized except where widespread accumulation of bark requires periodic dredging of larger areas. Barge dumps could cause major substrate disturbances in shallow water, but most barge dump sites must be in areas deep enough to allow passage of large tugs, so the direct effects of this activity on bottom sediments are probably small.

Dumps of bundled logs are more likely to disturb substrates than dumps of loose logs because bundles sink deeper before floating. The proportions of logs that are dumped loose or in bundles differ markedly by region. For all of coastal British Columbia, about 69% of the cut is bundled before dumping (FERIC 1980). In southeastern Alaska, over 99% of the timber cut is dumped as bundles (Faris and Vaughan 1985).

Faunas are expected to be depleted in the relatively small areas where logs come in contact with the bottom during dumping. Among species that could be affected are clams, crabs, oysters, sedentary polychaetes, and many other animals that depend on macrophytes that may be eliminated such as eelgrass *(Zostera marina).*

Several authors have observed or suggested effects 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 effects on eelgrass meadows as well as on the macrobenthic and microbenthic algae, but did not provide details regarding the type and extent of this damage. Physical disturbances to substrates may also result when lost logs become stranded along shorelines and on beaches and when log dozers create propeller wash during sorting operations. Narver (1972b) and Trethewey (1974) suggested that either propeller wash or dragged logs had gouged the substrate in and near the larger eelgrass beds in the Nanaimo estuary. Tug propeller wash during transport of flat rafts and bundle booms in the Nanaimo River estuary has scoured substrates to depths ranging from 0.5 to 1.5 m, although scoured areas gradually fill in with sediments transported by the river (Fish Habitat and Log Management Task Force 1980). The grounding of bundle booms during towing in this estuary contributes to additional scouring and the accumulation of inorganic debris (rafting cable and bundle fasteners), which causes (among other effects) windrowing of oysters and washout of clams (Duva1,et al. 1980). Naiman and Sibert (1979) reported that scouring of sediments in the Nanaimo estuary had severely limited benthic primary production, but provided no quantitative data to support their view. Other studies of log storage in the Cowichan, Chemainus, Campbell, Squamish, and Kitimat River estuaries, British Columbia, have indicated similar results (Levings and McDaniel 1976; Bell and Kallman 1976a, 1976b; E.V.S. Consultants Ltd. and F.L.C. Reed and Associates 1978).

The morphologies and growth patterns of aquatic plants affect the likelihood that they will be removed by substrate disturbances. Perennial plants that can regenerate from roots or holdfasts have a better chance of surviving after disturbance than those that require a portion of blade or frond for regeneration. Annuals will not reestablish themselves in a given year if they are removed by substrate compaction or scouring before their reproductive period. Eelgrass is a very common inhabitant of soft, muddy substrates in coastal British Columbia waters, substrates that also support several species of red, green, and dwarf brown algae in some areas (Scagel 1971; Ranwell 1972). Abrasion of eelgrass and emergent vascular plants by logs in these soft substrates probably fragments or uproots them. 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.

Physical disturbance to substrates at log-storage sites has only been documented in intertidal storage areas where log booms or bundles "ground" during low tide. In scuba surveys conducted by Ellis (1973) under floating log rafts in Hanus Bay, Alaska, no distinguishable differences were observed in the character of substrates from those in control areas. Pease (1974), however, reported that in an intertidal log-storage area, portions of the bottom contained 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 and Snohomish rivers in Washington (Levings and McDaniel 1976; Smith 1977) and the Nanaimo River (Sibert and Harpham 1979). In the Squamish estuary, sediments on beaches were abrased and scoured by logs that came to rest at low tide, and further disrupted when logs were towed on and off the beach. 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 grooved, up to 15 cm deep, parallel to the stored logs. They also noted that movement of bundle booms by tugs contributed to substrate scouring and subsequent release of hydrogen sulfide. Smith (1977) also reported the presence of troughs and ridges caused by grounding of logs in the Snohomish River estuary. Bundle booms, because of their greater draft, are more likely to disturb intertidal substrates than other types of storage, although bundling also minimizes disturbances resulting from log sinkage. Some operators, however, locate storage facilities in sheltered areas with sufficient water depths to prevent grounding of bundles or flat rafts at all times.

Plant communities on both rocky and soft substrates may be damaged as a result of such activities. At Bath Island, Georgia Strait, loose logs removed all algae from flat table rocks but generally not from vertical faces or crevices in the rock (Duval et al. 1980). In an attempt to simulate and assess the long-term effects of log abrasion on an algal community, DeWreede (cited by Duval et al. 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.* 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. In such disturbed areas, changes in abundance of invertebrates, species composition of invertebrate communities, or both have been significant and measurable.

Data describing the effects of disturbance on intertidal invertebrates by the accumulation of lost logs is limited (Dayton 1971), although both positive and negative influences are likely. When salvage operations are undertaken to recover lost logs, physical effects on shoreline areas are relatively short term and small. When stranded logs are left in rocky areas, however, they may crush organisms, particularly if they shift repeatedly to different areas on subsequent tidal cycles. On gradually sloping shorelines where most log accumulations occur (Waelti and MacLeod 1971), substrate compaction may affect the infauna (animals living within the substrate) in the same way as log grounding affects it in intertidal storage areas. Sediment compaction caused by the repeated grounding of log booms during low tides may prevent substrate use by larger suspension feeders such as clams and result in a shift to predominately infaunal detritus feeders; sometimes the whole benthic infauna is crushed and eliminated (Pease 1974; Smith 1977; Zegers 1978; Sibert and Harpham 1979). 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 (Pease 1974) and in Washington (Smith 1977) also indicate significant decreases in the abundance of benthic epifauna (animals living on the substrate or on other organisms) at intertidal storage sites where sediment compaction had occurred over prolonged periods. Zegers (1978) found 88–95% reductions in the total number of benthic organisms on areas of Coos Bay, Oregon, subject to log grounding.

In contrast, Sibert and Harpham (1979) observed no adverse effects of intertidal log storage on benthic epifauna in the Nanaimo River estuary. They found a greater density of epibenthic harpacticoid copepods (an important prey species of some 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 their study, Sibert and Harpham (1979) did suggest that infaunal habitat was probably reduced by sediment compaction.

Some intertidal organisms may benefit from log-debris accumulation in the intertidal zone. For example, the amphipod *Anisogammarus confervicolus* and the isopod *Exosphaeroma oregonensis* are extremely abundant within and adjacent to decomposing logs and wood debris in the mud flats of the Squamish River estuary, Washington (Levings and McDaniel 1976), although deeper areas in the substrate characterized by high concentrations of hydrogen sulfide are devoid of macrofauna (Duval et al. 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" (Waelti and MacLeod 1971). In an extensive comparative study of epibenthic invertebrates in a log-storage site and a natural marsh off the Fraser River estuary, British Columbia, Levy et al. (1982) found distinct habitat-specific differences in the distribution and abundance of certain resident species, although a total negative effect associated with the disturbed site was not observed.

Bark and wood debris accumulations.—The deposition of bark and wood debris at log dumps has been examined or discussed by several authors, including Ellis (1973), Schaumburg and Walker (1973), Pease (1974), Conlan (1975, 1977), B.C. Ministry of the Environment (1976), and Schultz and Berg (1976). The subject of most intensive investigation has been the abundance and distribution of wood debris under log-storage areas. 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).

In a scuba survey of four log-dump sites in coastal Alaska, three of which had been abandoned for two or more years, divers observed Considerable variability in depth of bark and wood deposits between sites (Ellis 1973). One inactive dump site had only scattered deposits in bottom depressions up to 10 m deep; another had accumulations of debris several meters thick and apparently anaerobic. Debris accumulations were noted at water depths up to 23 m at two log dumps, and the effects of dumping were evident within a 45-m radius around the center of one site. Sibert and Harpham (1979) reported that accumulations of bark and other debris under log booms were localized and relatively small. They further noted that sediment particle size was smaller and organic content was higher in sediment samples collected under log booms than in control samples. These trends supported the earlier findings of Schaumburg and Walker (1973) at a log-storage site in the Yaquina River estuary, Oregon.

Sinking rates and dispersion of debris from log dumping are also 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% of the bark had sunk after 1, 30, and 60 d. Water currents near dump sites can move bark both while it floats and after it sinks.

In an extensive examination of eight log dump sites in southeastern Alaska, five of which had been abandoned, Pease (1974) reported that 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 60–90 cm deep, but only 5–8 cm of bark were found at a dump that had been active for only 1 year. Ellis (1973) found a similar correlation between the depth of bark deposition and the period of use at other southeastern Alaska dump sites. Pease (1974) also noted that the area of substrate covered by bark differed between active and abandoned sites. At the oldest active dumping sites (7–10 years), the bark-covered area extended at least 60 m from the point where log bundles were introduced into the water. At the sites that had been abandoned for 1–11 years, this radius was reduced to about 15–23 m. Scattered patches of white powder were observed attached to the bark at many 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).

In a study of 32 log-transfer facilities in southeastern Alaska, Schultz and Berg (1976) calculated that for 31 sites, the areas covered by bark ranged from 0 to 3.7 hectares. Recalculating these data, Faris and Vaughan (1985) obtained an average of about 0.8 hectares of bark accumulation for the 31 sites, with a mode of 0.4 hectares. At 13 sites, no measurable accumulation of bark or debris was found around the site; presumably, the material had been carried to deeper waters or covered by sediments, or had decayed. Faris and Vaughan concluded that conditions varied too much among the log-transfer locations to generalize about where and how much bark and debris would accumulate. In an earlier study of three active dump sites in southeastern Alaska, Ellis (1970) found that water currents affected the extent of bark deposition; although these sites had been used for 12 years, no bark and wood debris had accumulated. It has been suggested that bundling logs before dumping them results in less bark loss (Hansen et al. 1971; B.C. Ministry of the Environment 1976; Conlan 1977), although bark loosened during preparation and handling of the bundles may remain within the bundle and be deposited in areas where bundles are broken.

Conlan (1977) studied an active and an abandoned dump site at Mill Bay, British Columbia, and reported bark debris deposits of about 1 km^2 for each site, with heaviest accumulations (>15 cm) closest to the dumps. Considerable deposits persisted at the site that had been abandoned for 20 years, supporting observations of Ellis (1973) and Pease (1974) that dispersal of debris was slow from areas with poor water circulation. In none of these studies were currents measured directly, however; poor circulation was inferred from the remaining deposits. Earlier, Hansen et al. (1971) had found that bark debris was still evident in a coastal Oregon lake after 30-40 years.

TABLE 9.8.-Incremental percentages of bark dislodged during logging, unloading, and raft transport; ND = no data. (From Schaumburg 1973.)

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	ND	ND	6.2

Schaumburg (1973) studied the effects of species of log handled on the amount of bark loss; 17% of Douglas-fir bark was lost during dumping of loose logs, but only 6% of ponderosa pine bark, which is more tightly bound (Table 9.8). Schaumburg also examined the effect of dumping method on bark loss by Douglas-fir; losses averaged 17% for slide-ramp (parbuckle) and 7% for A-frame hoist (lift and lower) methods. Robinson-Wilson and Jackson (1986) examined the relation between bark loss and the method of transfer of bundled logs at five transfer sites in southeast Alaska. Bark loss was directly correlated with the velocity of the bundle just before it entered the water. If bark accumulation at transfer sites poses potential problems, cranes or low-angle slides with rails should be used because they result in the least bark loss.

Logs lost during handling activities are another considerable source of wood debris accumulations. These logs frequently remain afloat and subsequently become stranded along shorelines. The volume of natural debris (as well as of logging debris that does not result from handling) has not been well documented. In southeastern Alaska, most woody debris is natural (Beil 1974; Forest Engineering Incorporated 1982), but up to 90% of the woody debris on some British Columbia beaches has cut ends, indicating it originates from logging or construction. Waelti and MacLeod (1971) estimated that 680,000 m^3 of logs were lost annually in the coastal Vancouver Forest Region, and the Council of Forest Industries (1974, 1980) estimated that gross log losses throughout British Columbia, including sinkage, but excluding recoveries by the British Columbia Log Spill Recovery Association, amounted to 827,000 m^3. About 40% of these latter losses were eventually recovered by log-salvage permittees and others, another 35% (chiefly western hemlock) sank, and the remaining 25% were lost to beaches or open seas.

Evans (1977) noted that the greatest proportion (about 70%) of wood debris in Georgia Strait resulted from log-handling losses (Table 9.9). Western hemlock was always the primary species lost, particularly among the smaller logs. Recent moves by some companies to increase dry-land sorting, water bundling, or both have greatly reduced flat rafting and associated log losses. The Council of Forest Industries (1974) estimated log losses by species and log size for each of four basic handling methods; overall, barging and flat rafting of loose logs produced the highest loss rates (Table 9.10). Waelti and MacLeod (1971) reported that gently sloping beaches accumulate the most log debris; rocky, steep shorelines trap relatively few logs. They further classified beach debris into three "age-groups": transient material lying below average high tide, which may be naturally removed within one change of the tide; material lying above the 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 normal high-tide

TABLE 9.9.-Sources and volumes of logs and debris in Georgia Strait. (From Evans 1977.)

Source	Volume of logs and debris (m^3)
Log transport and storage	297,000
Mills on Burrard Inlet and Fraser River	42,00-85,000
Howe Sound sorting	6,000-11,000

lines by extreme tides and wind. New drift makes up most of the beach wood, and old drift typically is at least partially decomposed.

Most of the effects of log-handling on benthic and intertidal invertebrates have been attributed to the accumulation of bark, wood, and other debris at transfer and storage areas, where they lie 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.

Studies of bark-deposit effects on plant communities are lacking, but a report by E.V.S. Consultants Ltd. and F.L.C. Reed and Associates (1978) showed that intertidal areas with heavy debris accumulation in the Campbell River estuary had fewer species of benthic plants than elsewhere and depletion of oxygen within the sediments; no adverse effects of log handling were observed in subtidal regions. Duval et al. (1980) summarized several reports that also suggested bark accumulations may result in decreased abundance of benthic micro- and macroalgae, although again, quantitative supporting data were lacking.

Pease (1974) examined algae and eelgrass communities 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 abandoned log-storage and dumping sites.

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 sandy bottoms in control areas with no debris had a wide diversity of organisms, including suspension-feeding bivalves and polychaetes. In areas with

TABLE 9.10.-Estimated log losses for each of four basic handling methods. (From Council of Forest Industries 1974.)

Log-handling method	Coastal production in 1974 (%)	Percent lost
Dry-land sorting and bundling, direct trucking to mills, or both	20	0.33
Water-bundling before towing to mills	23	1.7
Dumping, sorting, and flat rafting to mills	35	3.2
Barging of loose logs, dumping, and flat rafting to mills	22	6.1

debris accumulation, (1) suspension-feeding organisms were eliminated, (2) dominant benthic species were fewer and invertebrate biomass was less than in control areas, and (3) numbers of wood-boring bivalves *(Bankia* sp.) and isopods *(Limnoria* sp.) were greater than in control areas. 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. Conlan's results were generally consistent with those of earlier investigations of benthic infauna at active and abandoned log-handling areas (Pease 1974; Conlan and Ellis 1979) and demonstrated that, although the changes to infauna are not necessarily pronounced, they are measurable. Jackson (1986) found that macroinfauna densities and biomasses were lower in areas covered with bark, regardless of differences in depths between 3 and 6 and 7 and 10 m. Deposit feeders were less affected by bark deposits than suspension feeders. Additionally, considerable differences in species abundance were observed between depths at control sites, whereas sites affected by bark deposition showed no differences by depth except in the biomass of some species.

In general, the accumulation of bark and wood debris has had some, but not much, adverse effect on epibenthic communities. In areas with thick, soft deposits of decomposing bark but no sunken logs, Ellis (1973) found fewer epibenthic species (such as crabs) and attached forms (including anemones and tunicates). Pease (1974) reported similar adverse effects on both microalgae and eelgrass resulting from heavy bark accumulation and poor tidal flushing. Sometimes, light accumulations of debris may benefit some macroalgae (kelps) by providing more suitable substrates. At sites where scattered bark and sunken-log debris provided additional habitat, Ellis (1973), McDaniel (1973), Pease (1974), and Conlan and Ellis (1979) all reported increased abundances of epibenthic fauna, particularly amphipods, *Munida* sp., shrimp, crabs, anemones, and tunicates. However, in a comparative study of production by the amphipod *Eogammarus confervicolus* in three habitat types within the Squamish River estuary, British Columbia—a log-debris area, an embankment along a *Carex lyngbyei* marsh, and a *Fucus distichus* algal community—Stanhope and Levings (1985) found the highest mortality and lowest production in areas of accumulated wood debris, although they suggested that these areas may continue to provide sufficient food reserves for juvenile salmonids.

The evidence to date, therefore, suggests that suspension-feeding infaunal organisms are adversely affected by the physical changes associated with accumulation of bark and wood debris, whereas epibenthic organisms remain generally unaffected or sometimes may benefit from increased habitat. The epifauna seems to be adversely affected only where decomposition of bark debris creates a soft, flocculent substrate (Conlan 1977). O'Clair and Freese (1985) reported on a series of laboratory experiments with female Dungeness crabs *(Cancer magister)* exposed to bark debris from benthic deposits at log-transfer facilities in southeast Alaska. Feeding rates were higher in a clean sand control than in treatment sections with bark deposits. Bark deposits from a transfer site that had been inactive for 17 years caused higher mortality of Dungeness crabs relative to control animals, but fresh bark deposits did not. The percentage of eggs extruded was significantly lower in two of the four bark treatments than in the controls. Fecundities of Dungeness crabs on bark deposits at six log-transfer sites were reported to be only 44% of those of crabs found in the control sites. In addition, egg mortality was twice as great at log-transfer sites than at control sites and appeared directly related to an increase in the density of the parasitic worm *Carcinonemerges errans* Densities and sizes of Dungeness crabs were greater in control sites than in sites with bark, where there was a greater incidence of lost leg segments.

Light attenuation.—Many reports that discussed the effects of log handling on marine plant communities suggested that stored, floating logs create shade and that log dumping and sorting in shallow water increase turbidity. Although these types of disturbances undoubtedly occur, neither light intensity, spectral composition, nor water turbidity has been measured near log-handling sites, and adverse effects of these changes on plants have largely been inferred. Rates of primary production and standing stocks of plant communities affected by various aspects of log handling also have not been determined.

The effects of changes in light regimes probably vary among plant species and with seasonal differences in the light requirements of those species. Greatest effects likely are caused by shade under rafted logs. Decreased light intensity may reduce rates of primary production and growth, and may eventually lead to the loss of benthic microalgae and macrophytes from these areas. Free-floating plants (phytoplankton) would not be substantially affected by shading because they would not remain long in environments with reduced light. Reductions in plant community structure and abundance may affect various invertebrates that rely on these plants.

Particulate matter such as silt and fine bark debris may enter the water column as a result of log handling and raise the turbidity. When present in sufficient quantities, suspended particulates not only reduce light intensities, they also change the spectral composition of light by differentially scattering short-wavelength radiation (<500 nm). Both types of change cause decreases in the rates of photosynthesis and plant growth, but they are probably extremely localized and of minor concern for log-handling operations in coastal marine environments.

Chemical Disturbances

The major chemical consequences of log handling are increased biochemical oxygen demand (BOD), production of hydrogen sulfide (H_2S) and ammonia (NH,) during the decomposition of bark and woody debris, and release of soluble organic compounds (leachates) from logs. When present in sufficient quantities, leachates also exert an oxygen demand on and impart a yellow to brown color to the water. The decomposition of bark and wood debris in water proceeds in two phases: a relatively rapid process mediated by heterotrophic bacteria, followed by a slower one requiring lignin-decomposing fungi; the fungi are common in terrestrial ecosystems but not in marine environments. Decomposition in this slower phase, however, is often augmented by boring organisms such as Bankia setacea (feathery shipworm) and Limnoria lignorum, which give the fungi access to the interior of wood. The decomposition of bark and wood requires oxygen, and this process can locally deplete dissolved oxygen concentrations if there is no movement of water to impart fresh oxygen supplies. Anaerobic conditions are most likely to develop on the bottom, where currents typically are slowest. Currents greater than 0.01 m/s, however, prevent the biochemical oxygen demand of wood debris from having a notable effect on dissolved oxygen concentrations (Pease 1974). Such currents usually occur in the water columns of tidally influenced bodies.

To date, the chemical effects of log-handling on plant communities have not been examined, although both positive and negative effects are possible. Some authors have suggested that the chemical effects of bark and wood accumulations on benthic organisms are minor. Schaumburg (1973) and Pease (1974) reported that the BOD of these materials is low enough that oxygen levels in waters within or above the substrates are generally unaffected, or at least are not substantially changed from those normally associated with marine sediments. Similarly, the opportunity for dilution available in most log-handling areas usually prevents the accumulation of H_2S or wood leachates in the water column. Exceptions have been documented in poorly flushed areas where extensive debris has accumulated on the substrate. The potential, however, for chemical effects on benthic invertebrates in these areas is relatively high. A study by FERIC (1980) indicated that 4,208 hectares (47%) of log-handling lease sites examined in British Columbia were located in areas with negligible tidal currents. The BOD in such areas becomes a measurable and significant feature of the water–sediment interface, where circulation of oxygenated interstitial water may be reduced and bark deposits may accumulate.

The oxygen uptake of benthic bark deposits has been measured by McKeown et al. (1968), Schaumburg (1973), and Pease (1974). These authors reported daily oxygen demands of 0.2-4.4 g $0_2/m^2$. Schaumburg (1973) found that the oxygen demand of bark deposits in coastal Oregon waters increased with both the concentration of organic solids in the deposits and the 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 particle-size distribution and surface area of log debris. McKeown et al. (1968) indicated that mixing or water turbulence above the substrate increases the oxygen demand of benthic bark deposits by accelerating decomposition. Daily uptake ranged from 0.2 to 0.8 g 0,/m2 under stagnant conditions, but water movement above the deposits increased the demand to 2.7 g $0_2/m^2$. Gentle scouring of the benthic bark deposits further raised the daily oxygen demand to 4.4 g $0_2/m^2$.

Pease (1974) reported on one log-dump site in southeastern Alaska where low oxygen and high concentrations of H_2S 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 H_2S concentrations could not be distinguished from the concurrent physical changes in sediment composition. Conlan (1975) stated that quantitative information was lacking on the accumulation of leachates or H_2S 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 may have limited flushing potential. Sublethal or lethal chemical effects on plants would likely be restricted to benthic species in the immediate vicinity of these deposits and to both pelagic and benthic species near recently immersed logs still releasing leachates. Although H_2S is toxic to some species of fish (McKee and Wolf 1971), marine benthic infauna are normally exposed to H_2S produced by decomposition in the sediments and are unlikely to be greatly affected by the additional H_2S 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 H_2S that may accumulate in the water column of poorly flushed areas. However, no data are available on the toxicity of H_2S to epibenthic and pelagic marine invertebrates.

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 deposits in estuarine and marine sediments is primarily by means of sulfate reduction. This bacterially mediated process results in production of H_2S, various organic compounds, and carbon monoxide (CO). 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. Pyrite, formed from FeS, decreases the total sulfide capacity and increases the probability of free sulfide formation (Bella 1975). The tendency for the leached extracts from bark and wood to exhaust the iron in surface sediments is evident from the high concentrations of free H_2S present in benthic wood deposits (Pease 1974). Within undisturbed sediments, the FeS content increases as available organics are decomposed, inhibiting free sulfide production as long as it remains below the sulfide capacity. Physical disturbance or flushing of the sediment with aerobic waters oxidizes the FeS and releases the sulfide. As a result, the sediments undergo a series of cycles in which the FeS increases during periods of physical stability and rapidly decreases during sediment disturbance. Studies by Vigers and Hoos (1977) and Sibert and Harpham (1979) documented such processes in the Campbell and Nanaimo river estuaries of British Columbia as a result of tugboat-propeller wash from log-handling operations. At all log-handling sites, free sulfide inevitably forms if associated organic deposits are excessive and exceed the available iron capacity. Conlan (1973, however, cited only one instance when resultant H_2S concentrations reached toxic levels, which occurred when organic matter was buried under beach gravel (Hansen et al. 1971). Other laboratory studies with fish have shown that acute lethal concentrations of H,S have ranged from 0.8 to 7.0 mg/L depending on test species and pH (U.S. Environmental Protection Agency 1971).

Substantial amounts 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 they generally include tannins, resins, oils, fats, terpenes, flavanoids, quinones, carbohydrates, glycosides, 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). Some 60-80% of the chemicals leached from wood are volatile (Schaumburg 1973). Leaching is faster in salt water than in fresh water. In stable flowing water, the leaching process is nearly constant for at least 30 d (Hansen et al. 1971), but the leaching rate increases with the flushing rate and (when flushing rates are low) it decreases as the concentration of organics in the surrounding water builds up. The leaching rate also varies with the species and age of wood, the residence time of the wood or bark in water, and temperature (Atkinson 1971; Gove and Gellman 1971). Gove and Gellman (1971) 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, Alaska-cedar, western hemlock, and Sitka spruce. Schaumburg (1973) reported a decrease in the BOD of Douglas-fir leachates from 0.46 to 0.07 g $0_2/m^2$ daily after 25–30 d.

Of further concern is the potential for colored, light-attenuating leachates to reduce autotrophic production, although log leachates may have positive influences as well. Some constituents of wood leachates, such as glucose, may stimulate growth by plant species capable of heterotrophic uptake. This uptake, however, is not likely to be important for benthic microalgae adapted to low light and already relying primarily on heterotrophic production.

Schaumburg (1973) believed that the potential toxicity of log leachates to marine animals is negligible because of the tendency for lignin constituents to precipitate with divalent cations in seawater. Nevertheless, accumulation of leachates in freshwater or slightly brackish log-handling areas (such as the tidal portions of rivers) is of concern, primarily because of the effects of plicatic acid on the pH of these poorly buffered waters (Peters 1974). Furthermore, laboratory studies of marine and freshwater invertebrates by Buchanan et al. (1976) and Peters et al. (1976), respectively, indicate that log leachates can have toxic effects that vary with the species of tree and the species and life stage of invertebrate. Pease (1974) conducted similar studies both in the laboratory and in the field, recording the highest leachate concentrations observed in nature: 280–320 mg/L in a poorly flushed Alaskan log-storage site. These concentrations were about five times the threshold concentrations for acute toxicity to pink salmon fry determined in the laboratory. No bioassays were conducted at the log-storage site to determine if the receiving waters were actually toxic to benthic fauna, however.

Consequences of Log Handling and Storage Operations for Fish

Having described the primary physical and chemical effects of log-handling and storage on estuarine and intertidal biotic communities, we turn now to particular consideration of fish. Fish species that may inhabit the areas most frequently used for log handling (estuaries, sheltered bays, and inlets) include the anadromous salmonid species (Pacific salmon, cutthroat and rainbow trout, Dolly Varden), marine smelts (surf smelts, capelin, longfin smelt, eulachon), Pacific herring, various rockfishes, and bottom-dwelling species. Some of these species have commercial and recreational importance, and many of them are important prey 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 these phases for some important fish species in Pacific Northwest coastal waters is presented in Table 9.11.

The direct effects of log handling on fish have not been quantitatively assessed except by Levy et al. (1982). The following sections therefore describe probable effects of log handling, based on observations of other communities such as

TABLE 9.11.-Life history phases of some important fish species in British Columbia coastal waters.

Species	Activity	Month											
		J	F	M	A	M	J	J	A	S	O	N	D
Salmonids	Fry and smolts estuary residence"	—	—	—	—	—	—	—	—	—	—	—	—
	Adults, migration staging	—	—	—	—	—	—	—	—	—	—	—	—
Pacific 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			—	—	—							

"Information on timing from Hart (1973).

benthic invertebrates, and on indirect evidence of effects cited in the few references available on this topic.

Direct effects.—The most comprehensive study of fish densities, growth, and feeding behavior was conducted in the Fraser River estuary, British Columbia, (Levy et al. 1982). Within the north arm of the estuary, a pristine marsh was compared with a marsh with extensive log-storage booms. Levy et al. (1982) found salmonid densities to be similar in both areas, and they concluded that juvenile salmon did not avoid booms of stored logs in this well-flushed estuary. They also found that chinook salmon fry in the Bog-storage area were substantially larger than in the pristine marsh site. The size of chum salmon fry did not differ between log-storage and pristine marshes.

Juvenile salmon in two adjacent intertidal areas of the Fraser River estuary-the Point Grey log-storage area and the Musqueam Marsh—displayed major dietary differences (Levy et al. 1982). A dietary shift in the log-storage area appeared to be caused by a decrease in estuarine insects, because marsh plants were absent there, and by a greater availability of fish larvae and the mysid *Neomysis mercedis*. Levy et al. (1982) concluded that "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 that could be attributed to the presence of stored log booms." Because the Point Grey log-storage area is well flushed, the authors suggested that research is needed to test the hypothesis that fish also do not avoid log booms in poorly flushed areas.

Potential direct effects of log handling on fish may result from physical disturbances associated with transfer and sorting activities. For example, bark accumulations may suffocate incubating eggs of nonsalmonid species or interfere with other uses of habitats by fish. Chemical effects may be exerted by leachates released from stored logs and by 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 juvenile salmon rear in many rivers, estuaries, and coastal areas, and adults aggregate there during spawning migrations to natal streams (Neave 1966; Scott and Crossman 1973; Stasko et al. 1973; Levy et al. 1979). Anadromous cutthroat trout, Dolly Varden, and steelhead may use some of these coastal environments throughout the year (Scott and Crossman 1973). Other species, including smelts and herrings, may concentrate in estuaries, inlets, and bays during their spawning and migration periods (Table 9.11). Only the surf smelt, capelin, and Pacific herring spawn and deposit eggs in marine environments potentially used for log handling, however (Hart 1973). Quantitative assessment is impossible because direct effects of log handling on fish have not been studied. Log-transfer and -sorting activities, however, are unlikely to interfere substantially and directly with fish outside the relatively small area where the disturbances occur, and fish would probably avoid such areas. Nevertheless, log dumping, tugboat propeller 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 effects 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 Schaumburg (1973) and Pease (1974). In laboratory experiments, log leachates were toxic to fish and also raised the biochemical oxygen demand in the water. The toxicity of leachates is significantly lower in sea- and brackish-water environments than in fresh water, however. Both Schaumburg (1973) and Pease (1974) 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 log-dumping and storage areas examined by Pease (1974) in southeastern Alaska, only one 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 high proportion (47%) of coastal British Columbia log-handling sites reported to have negligible tidal flushing (27% have depths less than 3 m: FERIC 1980) suggests that direct chemical effects of this type may occur in some areas.

Indirect effects.—Alterations in fish habitat or in the abundance of fish prey may indirectly affect fish populations either positively or negatively. For example, many intertidal or estuarine log-handling sites in British Columbia support communities of eelgrass or rockweed or both, which are common substrates for deposition of Pacific herring spawn (Outram and Humphreys 1974; Patterson 1975). Several authors have suggested that the abundance of aquatic flora has been dramatically reduced in some intertidal areas used for log storage through shading (B.C. Ministry of the Environment 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 by tugboat activity (Sibert 1978). These effects may be responsible for elimination of herring spawn deposition in Ladysmith Harbor near Dunsmuir Island (Patterson 1975) and in the Mamquam Channel area of the Squamish River estuary (Hoos and Vold 1975). No evidence suggests, however, that the population of Pacific herring has declined as a result. 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.

Declines in the abundance of benthic epifauna and infauna, which may be important fish food, have been reported in some areas where bark and wood debris accumulate or where intertidal log storage occurs (Ellis 1973; Pease 1974; Conlan and Ellis 1979); fish populations using these nearshore environments could be indirectly affected. Conversely, some prey organisms may become more abundant in areas of scattered log debris and bark. For example, Levings (1973) noted large populations of amphipods *(Anisogammarus pugettensis)* 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 effects of log handling have been recorded in the Kitimat River estuary, British Columbia (H. Paish and Associates Ltd. 1974; Higgins and Schouwenberg 1976). Conlan (1977) also reported that the abundance of amphipod species is either increased or unaffected by log storage.

Herrmann (1979) calculated the effects of log-rafting sites cn benthic invertebrates and fish production in all of Coos Bay, Oregon. He estimated that the summer benthic invertebrate biomasses were 2,050 kg (dry weight) on 85 hectares of intertidal log-storage areas, 64,370 kg in the upper bay, and 257,000 kg on all of the Coos Bay tideflats. He further estimated that the 2,050 kg of benthos in the storage areas could support production of about 1,370 kg (live weight) of fish tissue — about 0.6% of fish production estimated for the entire Coos Bay tidal area.

Although some authors have inferred that compaction of sediments under intertidal log booms has contributed to a decrease in benthic amphipods and copepods that are major prey of juvenile salmon (Healey 1978; Waldichuk 1979), this relation has not been satisfactorily demonstrated. Sibert (1978) and Sibert and Harpham (1979) reported that although larger infaunal species disappeared from log-storage areas of the Naniamo River estuary, the total abundance of major meiofaunal taxa, nematodes, and harpacticoid copepods (important prey of juvenile chum salmon) could not be related to the presence of log booms.

Some observations further suggest that some fish species, including prey species of marine mammals, may be attracted to areas where wood and bark debris increase the abundance of food sources. Ellis (1973) found Pacific sand lances, blennies, sculpins, and yellowfin sole in areas of undecayed bark and debris under log-storage areas in Hanus Bay, Alaska. Schultz and Berg (1976) also reported fish species such as Pacific cod, shiner perch, rockfishes, and searcher in association with submerged logs, branches, and benthic deposits in southeastern Alaska.

Such evidence suggests that log-handling operations may not be responsible for substantial reductions in fish habitat and fish-food organisms. One frustrating aspect of our concern for the environment is the lack of research data to support decisions. With the exceptions of Coos Bay and the Nanaimo River estuary on southeastern Vancouver Island, no comprehensive ecological study of log-rafting and -storage effects on a total estuary has been conducted. 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

The assessment of effects of log handling and storage on biotic communities is hampered by the lack of quantitative information on plant communities, chemical stresses, and community interrelationships. Another problem is the difficulty of distinguishing between the effects of two or more concurrent forms of disturbance. The degree of disturbance is largely determined by the spatial extent of a log-handling operation and its location with respect to potentially sensitive areas such as estuaries.

Physical and chemical perturbations are the two primary disturbances associated with log-handling operations. Physical disturbances include substrate scouring and compaction, modification of sediment composition, accumulation of wood and bark debris, alteration of light levels, disruption of the water column, and increases in turbidity. Chemical disturbances include changes in water quality, decomposition of wood debris deposits, leaching of potentially toxic chemicals from wood, and deoxygenation of water and substrate.

Log-dumping and -sorting activities and the storage of logs in sensitive intertidal areas are considered the most detrimental aspects of log handling to biotic communities. Such operations have destroyed benthic habitats and crushed benthic organisms, altered the composition and abundance of benthic infaunas, disturbed substrates for eelgrass and emergent plants, reduced levels of light needed by primary producers, and diminished water quality through leachate activity and wood-debris accumulations, Tables 9.5 and 9.6 summarize these effects on plant and invertebrate communities. Although it appears that most effects are detrimental to aquatic environments (particularly estuarine environments), there are some positive influences as well. These include increased habitat complexity for some benthic organisms that is provided by light accumulations of wood debris and the potential for enhanced heterotrophic production by those plants that can metabolize chemicals leached from wood.

Log-handling and -storage activities can have either direct or indirect effects on fish habitat and abundance, as summarized in Table 9.7. The extent of log-handling and -storage operations throughout the northwestern USA and western Canada must be determined so we can better understand their effects on the fishery resource. Many of the alleged negative effects of log handling on fish are speculative, based on few observations and fewer quantitative studies. The degree of harm to the fish resources of coastal British Columbia and southeastern Alaska probably ranges from insignificant to minor. The greatest potential detriment is destruction of Pacific herring spawning areas. Some observations suggest that fish may receive positive indirect benefits from log-handling operations in the form of more abundant invertebrate prey in areas where log debris accumulates.

The degree to which local environments and fish populations are affected by log-handling and -storage operations depends in large part on the size of the disturbed area, local flushing characteristics, and water depth. A study of log-handling leases in coastal British Columbia waters by FERIC (1980) indicated that 27% of them (totaling 2,400 hectares) were less than 3 m deep, and that 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, subsequently affecting secondary production by invertebrate grazers. It can be seen, therefore, that such effects on a local environment generally have deleterious consequences for more than one species. Once the biotic community structure is so altered, organisms at higher trophic levels (fish) will likely be affected as well.

Information Gaps and Research Recommendations

Much 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 from dumping and stray logs. This information has been used to help 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 for survival of anadromous salmonid stocks in western North America and that any disturbance to the estuary is detrimental, no matter how small the area affected.

Although data show that only a small fraction of the total available estuarine area might be affected by log-handling operations, there is good reason to locate these operations on the least damageable portion of each estuary. We are only just beginning to understand the role that certain areas of the estuary play 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, it is impossible to say how this has affected salmon runs. 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. Further, all along the 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 to support the increased numbers. Clearly, the consequences of allowing estuarine areas to be destroyed are highly uncertain, and valuable salmon runs could be put in jeopardy. This uncertainty about the adequacy of estuarine areas for salmonids is likely to persist in the immediate future, despite the best research efforts. The estuarine and marsh areas and the salmon runs associated with them are complex, and the life cycles of salmonids that use estuaries both as juveniles and as adults can last four or more years.

These characteristics make the research task difficult, lengthy, and costly. Currently, our technology and organization of research is poorly developed to meet the challenge.

Planning for log transportation, whether by 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 reflects what can reasonably be developed in a short time and does not falsely imply that effects on salmon can be measured in a short time.

From our review of the literature, the evidence is inconclusive about the importance that small areas of the size affected by log transfer and storage have for the 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, great caution must be used when evidence from one estuary is applied 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 if one is to 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 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, clams, and oysters.

Dry-land alternatives to freshwater or marine log transfer and storage may permanently damage both upland and shoreline habitats. Facilities that allow logs to be transferred to and from barges without touching the water may require permanent structures that displace nearshore marine habitat with pilings and rock fill. Onshore 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).

Marine birds and mammals use log rafts as feeding and resting stations; birds use them as nesting areas. Older rafts in fresh water with brush growing on them also may be used by terrestrial birds and waterfowl for nesting. Both the birds and mammals are vital components of the ecosystem; the relations between these organisms and log rafts—and the consequences of raft removal—should be studied.

Except for cursory observations, the importance of log rafts as habitat or protective cover for fish has not been well documented. We need to determine whether storage and dumping areas provide substantial 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 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 such disruptions has not been documented or quantified. Because the potential for such negative effects as resuspension of toxic materials or damage to benthic habitat should be weighed against the positive result of retrieving salvageable logs, an examination should be made of the extent of area affected by retrieval operations, maintenance dredging, and activities of vessels in log-handling areas.

In general, less emphasis should be placed on studying effects that have already been described because regulations are in effect or are being developed to alleviate them. Both positive and negative effects not previously studied should be given more emphasis, particularly relative to the entire ecosystem. Research priority should be given to areas of poor water circulation because effects of log handling are 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 et al. 1971; approved by the Pacific Northwest Pollution Control Council), were designed to minimize the effects of log handling on the aquatic environment and remain 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.
- Control of bark and wood debris, including proper collection and disposal methods, should be used at log dumps, raft-building areas, and mill-side handling zones for both floating and sinking particles.
- Log dumps should not be located in rapidly flowing waters or other zones where control of bark and debris 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 permit the floating of bundled logs, logs should be secured in bundles on land before being placed in the water. Bundles should not be broken again except on land or at the mill.
- The inventory of logs in water for any purpose should be kept to the lowest possible number for the shortest possible time.

Additional site-specific measures can be applied to a particular operation to ensure protection of aquatic habitats (Toews and Brownlee 1981), depending 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: (a) resource values present (e.g., shellfish, herring spawn, emergent vegetation, salmonid rearing); (b) physical characteristics of site (e.g., substrate, depth, currents, tidal flushing).

- Details of proposal: (a) dumping, sorting, and transport methods; (b) log volumes and inventory, seasonal log flow; (c) duration of operation (usually related to upland logging); (d) positive debris-control measures (recovery and disposal of both floating and sinking debris).
- Potential effects based on the above considerations for both proposed and alternative sites (alternative sites may include those on dry land).