FISH AND SHELLFISH RESOURCES OF WILLAPA BAY OF INTEREST TO THE SHOALWATER TRIBE

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FISH AND SHELLFISH RESOURCES OF WILLAPA BAY OF INTEREST TO THE SHOALWATER TRIBE

The purpose of this report is to provide the Shoalwater Tribe with information on the current status and potential production of the commercially valuable finfish and shellfish species of Willapa Bay. Questions to be answered include current degree of reliance on artificial production, geographical distribution of the resource, production trends over the last ten to fifteen years, economic and biological factors responsible for these trends, and potential for increased harvest. The potential for cultivating presently unutilized shellfish species is also discussed.

STATUS OF RESOURCES

I. Finfish

A. Salmon and Steelhead

Willapa Bay supports three species of salmon: fall chinook, coho, and chum. All steelhead returning to the bay are winter run (that is, return to the river occurrs between November 1 and April 30). Two fisheries operate within Willapa Bay and its tributaries: the non-Indian commercial fishery and the sport fishery. The commercial fishery consists exclusively of drift gillnets. This fishery is concentrated in the outer waters of the bay, although several areas closer to the streams entering the bay are also fished. The sport fishery is by hook-and-line and operates in the rivers themselves. Most sport effort is directed toward steelhead, although salmon are also caught. Sport salmon catch is low relative to the commercial catch (14% of the total catch of local chinook stock, 12% of the coho, and 3% of the chum since 1982).

1. Status of Willapa Bay runs

a. Runs managed for hatchery production and natural production

Salmon. Willapa Bay chinook harvest rates are limited by hatchery escapement requirements, consistent with the high (about 62%) percentage of hatchery fish in the escapement (Figure 1). No directed harvest has been allowed on this species in recent years, because the coho and chum fisheries have incidentally harvested the available surplus. These measures resulted in a slight surplus in the hatchery escapement for the first time in 1984 (Figure 2).

Management of Willapa Bay coho harvest is also based on hatchery production. Hatchery fish make up about 90% of the Willapa Bay run (Figure 3). Hatchery escapement has generally been satisfactory (Figure 4), so directed fisheries have generally been allowed. WDF has also attempted to use the natural rearing capacity of the Willapa watershed by outplanting coho fry in years when when hatchery surpluses exist. To aid in increasing natural production, habitat improvements have been installed on the North River.

Harvest of Willapa chum is managed for natural production. Hatchery fish make up a relatively small portion of the run (Figure 5). Escapement goals have generally been met in recent years (Figure 6), so a targeted fishery is usually conducted for this species.

Steelhead. Sport regulations reflect management for harvest of hatchery production early in the season (December through February) and some degree of protection for the wild run later in the season. This takes into account the considerable numbers of early-returning hatchery fish that have been stocked since the early seventies. Consequently, winter season sport harvest occurrs until the end of February on most of the Willapa Bay tributaries. Exceptions are parts of the Naselle and Willapa Rivers, which are open until the end of March. However, no data apparently exists regarding the hatchery-wild composition or the timing pattern of the two components of the run.

b. Trends in catch, escapement, and run size of Willapa stocks over the years for which information is readily available.

Salmon. The hatchery run of chinook has exhibited no definite trend since 1974. 1973 saw a very large return (Figure 1) which has not been approached since. Hatchery run size has borne little relation to the increasing releases of hatchery stock (Figure 1 and 7). The fraction of the run harvested was low in 1983 and 1984 due to efforts at building up the hatchery returns. Higher escapements (9,000 fish goal) are desired in the coming years to build up the Naselle Hatchery run to its rearing capacity. Such high levels of escapement to Willapa Bay were not needed in previous years, when the Naselle hatchery was not in operation. The hatchery escapement goal at that time was between 4,000 and 5,000, and was usually met. Exceptions occurred in 1981 and 1982, when some chinook escapement was sacrificed for efficient harvest of strong hatchery coho runs. Since 1983, the time and area of the chinook fishery has been adjusted to reconcile the two objectives, as explained above. As a result, the 1984 fishery provided an efficient harvest of coho while still meeting the chinook escapement goal.

The run size for hatchery coho has exhibited an increasing trend since the late seventies (Figure 3). This corresponds to the increase in releases of hatchery smolts during this period (Figure 8). Meeting hatchery escapement goals has usually not been an issue as it has with hatchery chinook. A hatchery coho escapement of 6,000 to 7,000 is desired to achieve full hatchery capacity.

The wild chum run size may have been increasing since the mid-seventies, but interpretation is difficult because very high run size occurred in only one year (1982) (Figure 5). Releases of hatchery stock have increased considerably over the last several years (Figure 9), but the hatchery component of the run is still relatively small (Figure 5). A wild chum escapement of 35,400 is desired to completely seed the watershed for natural production. This goal is being met with increasing frequency over the period reported here (Figure 6).

Steelhead. Sport catches (based on catch summary leaflets published annually by WDG in Olympia) have displayed no particular trend over the period since the early seventies (Figure 10). This is in contrast to the increased level of planting that has occurred since the late seventies (Figure 11).

c. Stocks which have regularly had harvestable surpluses

All four major species of Willapa Bay salmonids have had harvestable surpluses in recent years. The coho, chum, and steelhead runs support directed harvests. Production and harvest are expected to continue at present levels for the foreseeable future. In the case of chinook, hatchery production is expected to increase enough to support increased harvests by the end of the current brood cycle.

2. Distribution and timing of viable runs within Willapa Bay

a. Distribution of harvestable runs in terms of catch area

Salmon. Migration routes for runs within Willapa Bay cannot be determined from existing information. Most of the catch for all salmon species (Table 1) comes from a single area (Area 2G, Figure 12). This area encompasses the outer waters of the bay through which all runs pass. The predominance of Area 2G catch for all species is due in part to the ability of the existing fishing fleet to harvest this area more efficiently than the others. The relatively high coho and chum catches in this area are the result of WDF regulations to concentrate fishing effort here for those species. This effectively reduces pressure on the local chinook, which have cleared Area 2G by the time the coho and chum fisheries have begun.

A few differences in species distribution among the remaining areas (2H, 2K, 2J, and 2M) can be seen (Table 1). These

Table 1. Salmon catch composition by catch reporting area, mean of 1982-84.

Area	Total Catch	Species Composition		
		Chinook	Coho	Chum
2G	81,551	5.0	42.0	53.0
2H	5,398	10.2	76.5	13.3
2K	2,714	2.7	38.6	58.7
2J	4,182	4.9	43.5	51.5
2M	8,606	14.7	37.2	48.2
Combined	102,451	6.1	43.4	50.6

differences seem to correspond to varying production of certain species in the various watersheds. For example, chinook contribution to the catch in Area 2M (Figure 12), and to a lesser degree in Area 2H, was a larger percentage than chinook contribution to the bay as a whole. This probably reflects a higher production of chinook in the Naselle and Willapa rivers. Coho contributed a much larger percentage of the catch in Area 2H than in the bay at large. This reflects the large hatchery coho releases in the Willapa River. Coho distribution is expected to change as WDF's new Naselle River Hatchery reaches full production.

In the case of the hatchery runs, the best predictor of distribution may be the relative size of releases of hatchery stocks in the various tributaries of Willapa Bay. In recent broodyears (1980-83), chinook releases have been made from three WDF hatcheries, the Willapa Hatchery contributing about 37% of the releases of fish greater than 150/lb. the Nemah Hatchery contributing 23%, and the Naselle Hatchery 40%. In the case of coho, the average percentages for the 1980-82 broodyears were 23% from the Willapa Hatchery, 27% from the Nemah Hatchery, and 50% from the Naselle Hatchery.

Steelhead. The steelhead catch distribution over the same period (1982-84) is shown in Table 2. The Willapa River contributed over half the catch, and the Naselle River about a quarter of the catch.

b. Timing of the Willapa Bay catch

Salmon. The salmon fishery can potentially operate from early July through November. Non-local chinook are the first to enter the catch in early July. This group of fish usually clears Willapa Bay around mid-August. Local chinook begin to enter the bay in early August, becoming more important in the run than non-

II. Shellfish

A. Oysters

The Pacific Oyster (Crassostrea gigas), an introduction from Japan, is the only species of oyster commercially cultivated in Willapa Bay. Willapa Bay is one of the largest oyster-producing areas on the Pacific Coast (Proctor et al., 1980), and oysters dominate the poundage and economic value of Willapa Bay shellfish harvests. An average of 2,969,000 pounds were harvested over the 1980-1984 period (Ward and Hoines, 1985). This is about 50% of the Washington state total.

1. Source of Production

Commercial production on all Willapa oyster grounds is dependent on artificial reseeding. "Seed" means juvelile oysters approximately a half inch in diameter, usually attached to pieces of old shell, and ready to be placed in growing areas. Naturally-produced seed from areas near the mouth of the Naselle River and Long Island are not sufficient, so most seed is brought in from Dabob and Quilcene Bays in northern Hood Canal. Some hatchery-produced local seed from Bay Center and Nahcotta is also used. Seed production is determined by the amount of "set", or "spat fall." This is the settling of juvenile oysters (called spat) onto the surface of empty shell pieces (called cultch) which have been placed in the water to collect spat.

2. Distribution

Oyster production occurrs throughout the intertidal area of Willapa Harbor (Figure 18) from tidal elevations of +3.5 feet above mean lower low water down to -1.5 feet. Most oysters are grown on the bottom (bed culture), although a small amount are grown off the bottom. In either case, oysters must be grown to marketable size and have meat of marketable quality. Certain areas of the bay are better suited toward accomplishing one or the other of these goals. Growing areas (Figure 19) are those best suited for increasing the size of the oysters. Upon reaching marketable size, oysters from most of the growing areas must be moved to fattening areas (Figure 20).

In general, growing areas are closer to the tributaries of the bay and fattening areas are closer to the ocean or are on the edges of the channels. This suggests that the bulk of the oysters' food supply (microscopic plant life suspended in the water and known as phytoplankton) comes in with the tide. Hedgpeth and Obrebski (1981) have suggested that oysters in the outer areas of the bay deplete the food available to those located closer to the rivers, thus making fattening impossible in those areas.

Table 2. Steelhead sport catch distribution, mean of 1982-84.

Location	Catch	Percentage
Smith Creek	104	3.1
North River	226	7.2
Willapa (including South Fork)	1,802	55.6
Palix	26	0.6
Nemah (North, Middle, and South)	198	6.3
Naselle	1,058	27.3

local stocks by the third week of August and peaking in the second week of September. Coho enter the fishery in the first week of September and peak catches generally occur in the first week of October. Chum enter the fishery about the first week of October and a definite peak in the catch occurrs between the third week of October and the first week of November. Overlap in the timing of the three salmon species is shown in Figure 13.

Steelhead. The timing of steelhead in the sport fishery is shown by monthly punchcard returns (Table 3). Timing is usually variable from year to year depending on the fishability of the rivers, which in turn are determined by weather conditions. Monthly catch records indicate that most of the catch occurrs from December through February with highest catches occurring in January. This relatively early timing is typical of WDG hatchery stocks. The hatchery/wild composition of the Willapa River run was examined in the 1977-78 season (Collins et al 1979). Occurrence of dorsal stubbing was recorded during creel census. On this basis, the catch consisted of about 65% hatchery fish from November through January and 49% hatchery fish in February and March.

c. Management of overlapping runs.

The effect of chinook dip-ins on the allowed harvest of Willapa runs has been an important issue. A dip-in may be defined as a fish which enters Willapa Bay in the course of migration to its parent stream outside the Willapa watershed (usually lower Columbia River "tule" stocks, especially those bound for the Spring Creek National Fish Hatchery). Dip-ins are a management issue because they are present in the bay when the Willapa runs are beginning to return. To the degree that the Columbia River runs are more in need of conservation than the Willapa stock, steps have to be taken to fish the two stocks separately. Lower Columbia River stocks have not met hatchery escapement goals in the last several years. Fortunately, some degree of separation in time and geographical distribution has made it possible to harvest the groups separately, with an acceptable degree of mixing. This separation results from the dip-ins' tendency to

Table 3. Steelhead sport catch timing, mean of 1982-84.

Month	Catch	Percentage
Nov	29	1.0
Dec	916	23.4
Jan	1,280	39.1
Feb	828	24.5
Mar	371	12.1
Apr	0	0.0

enter the bay earlier than the local run. The dip-ins also tend to mill in Area 2G without entering the other areas. In contrast, the local stocks are available for harvest in the inner areas of the bay (2H, 2K, 2J, and 2M). As a consequence, the catch of non-local stocks relative to Willapa stock has decreased dramatically in recent years (Table 4).

Another potential harvest conflict exists between local hatchery chinook and local hatchery coho. The hatchery chinook run has not always met the hatchery escapement goal. Because of the temporal overlap between chinook and coho, it has been necessary to restrict the coho fishery to Area 2G, as mentioned above. This has resulted in satisfactory hatchery escapement of chinook and slight overescapement of coho. Nonetheless, this strategy is considered by WDF to be the best available and will be employed if the situation persists in the future.

The hatchery coho and wild chum runs generally have both been strong enough to allow efficient harvest of both without impacting the escapement of either. In some years this has meant that all harvestable chum were taken incidentally to the coho fishery.

3. WDF and WDG analysis of harvest management data

WDF. WDF data analysis for harvest management has followed standard fishery management techniques. Harvest management is based on pre-season predictions of run size, in-season updates for coho and chum, and post-season evaluation of fish tickets and escapement. Pre-season predictions are based on historical data concerning the ratio of spawners in a given brood year to the number of returning adults. First, each year's run is divided into two segments, based on hatchery/wild composition of the escapement. Predictions are made separately for hatchery and wild components, except in the case of coho where the wild component is so small that its inclusion would add little to the accuracy of predicted allowable harvests. The historical database is further divided into odd and even years in the case of chum, to account for the apparent differences in productivity. Next, each year's catch is assigned to the appropriate brood

Table 4. Catch of local and non-local chinook.

Year	Non-local		Local	
	Catch	Percentage	Catch	Percentage
77	20,650	64.8	11,200	35.2
78	2,000	16.7	9,950	83.3
79	3,700	20.2	14,650	79.8
80	8,800	35.8	15,800	64.2
81	4,150	24.1	13,100	75.9
82	1,900	18.6	8,300	81.4
83	200	6.0	3,150	94.0
84	450	11.1	3,600	88.9

years based on scale analysis of the catch. From this data it is possible to calculate the historical rate of return per spawner.

At this point there are several different ways to predict chinook and chum run size given a particular set of broodyear escapements. WDF has not consistently used one method over the years, but has relied on intuitive judgement of the data. All alternatives are logically defensible. One alternative gives equal weight to all years in the database. This method uses the historical return/spawner ratio for each of the age classes expected in the run. Other alternatives give special weight to the brood year(s) that are due to contribute to the run in question. This is consistent with the observation that survival to three-year old adult is a predictor of survival to older age classes. Thus, for example, if last year's three-year-old return/spawner ratio was half the historical average, one would halve the historical average in predicting the contribution of four-year-olds to this year's run. Another alternative is to adjust the contribution of five-year-olds based on the average return/spawner ratio of three- and four-year-olds. Nonetheless, we do not believe this compromises the validity of the predictions, since all the methods used appear equally defensible.

The predictive methods appear to use the best available data. The effect of environmental factors on terminal run size has been investigated (D. Stone, personal communication), but temperature and salinity during outmigration and certain oceanic conditions bore no clear relation to terminal run size for any species.

Predictions for terminal runs of chinook do not account for marine interception. It is felt that changes in ocean fishing regulations do not have a strong effect on changes in abundance of Willapa stock (D. Stone, WDF, personal communication). However, we expect that future changes could increases the variability inherent in chinook predictions since significant interceptions are known to occur. At present, ocean distribution and interception patterns of this species are not understood well enough to model the effects on the terminal run. Research now being conducted pursuant to the U.S./Canada treaty might provide enough data to make such a refinement in predicting terminal run sizes possible.

In the case of coho, the accuracy of the prediction is probably enhanced by factoring in the marine interception. This is performed by the Harvest Management Division of WDF in Olympia upon receiving a preliminary terminal run size prediction calculated by the method described above. The database begins with 1979 when coho abundance increased over prior years because of changes in ocean fishing patterns. The 1983 data is not used because of the apparent effects of El Nino. Thus, the greatest criticism of the coho prediction is the limited number of years in the database. Nonetheless, this is probably the best use of the available data.

In-season updates are performed for the coho and chum runs. Genarally, one to three updates are done for the coho fishery and one for the chum fishery. These are based on a regression equation that relates each year's historical run size to the catch per effort for that year in a certain catch reporting area and during a certain week. To update the run size, the current catch per effort in the same area and during the same week is entered into the equation. WDF has thoroughly examined the various expressions of catch per effort to achieve the best fit of the equation to the data. This technique appears to make the best use of the data.

WDG. WDG has lacked the resources to conduct an analysis of the status of the Willapa runs. Catch data are based on punchcard returns, adjusted by comparison to creel census results. Some variability is inherent in this method because creel census, being labor-intensive, can be conducted only on a limited number of western Washington streams. However, this method is probably the best available given the limits on WDF resources. Escapement estimates are not available. Management of the sport fishery features closing dates that reflect a general concern over maintaining natural production of the late segment of the wild runs.

4. The US/Canada Treaty's effect on the number of fish available for terminal harvest in Willapa Bay

The US/Canada treaty is expected to increase the terminal run of Willapa Bay chinook, but to what degree is still unknown. Any conservation efforts will not be based on the condition of Willapa chinook and coho, which are in good condition relative to stocks of major river systems such as the Columbia.

The historical interception pattern consisted of high catches in southeast Alaska and off the west coast of Vancouver Island. All relevant tagging studies have been incorporated into an ocean interception model used by the WDF. This model is revised annually to reflect changes in fishing patterns.

B. Sturgeon and Bottomfish

1. Distribution and abundance

Green and white sturgeon both occur in significant numbers in the Willapa system. Tagging studies suggest that both these species belong to stocks which reproduce primarily in the Columbia River but regularly enter Willapa Bay and Grays Harbor. They are caught almost entirely as incidental catch in the salmon fishery. About 90% of the catch comes from Area 2G and nearly all the rest from 2J. There is no documentation of spawning in Willapa Bay or its tributaries. However, potential spawning habitat for white sturgeon may exist in the lower reaches of the Willapa and Naselle rivers, because they provide habitat similar to sturgeon spawning grounds in the lower Columbia (R. McIntosh, Washington Department of Ecology, personal communication). The spawning habitat requirements for green sturgeon are not well known.

The highest monthly catch of green sturgeon occurrs when fishing begins in July, and declines to a low in November (Table 5). This pattern is parallelled by catch per landing. Catch of white sturgeon exhibits a similar timing pattern (Table 6), but catch per landing does not. The high catch per landing in November and December is more likely explained by high variability due to low level of effort during these months, rather than to increased abundance of this species in early winter.

Catch trends for green sturgeon since the early seventies (Figure 14) have shown a definite decline that is closely reflected in the catch per landing data (Figure 15). Data for green sturgeon elsewhere are too limited to establish a trend. The apparent decline in Willapa Bay need not be attributed to a decline in the total population. Other factors could include annual variability in salinity of the estuary, or changes in the location, timing, and intensity of sport and commercial fishing effort.

Catch trends for white sturgeon since the early seventies (Figure 16) have shown an increase in catch but a decline in catch per landing since the mid-seventies (Figure 17). This apparent decline is peculiar to Willapa Bay. Stability of the total white sturgeon population is suggested by absence of a declining trend in the Columbia River commercial catch per landing and a stable size structure of the sport catch there (G. Kreitman, WDF, personal communication). Nonetheless, this situation could change if the increased fishing pressure seen in recent years continues.

The only flatfish of potential commercial importance is the starry flounder. Its low incidental occurrence in gillnet catches would suggest that this species is naturally scarce in

Table 5. Green sturgeon timing in catch, mean of 1970-81.

Month	Catch (lbs)	Catch (lbs) per Landing
Jul	343,056	285
Aug	293,064	127
Sep	77,475	88
Oct	23,681	56
Nov	1,373	76

Table 6. White sturgeon timing in catch, mean of 1970-81.

Month	Catch (lbs)	Catch (lbs) per Landing
Jul	72,153	107
Aug	75,409	66
Sep	39,926	57
Oct	20,405	63
Nov	20,327	163
Dec	3,451	690

Willapa Bay. However, gillnets are probably not very effective in capturing flounder, so that incidental gillnet catches may not be a satisfactory indicator of relative abundance. Dogfish are abundant enough that a commercial fishery once existed.

2. Potential for increased harvest

No data is available on the status of the sturgeon populations. As a consequence, WDF has historically chosen to maintain the existing fishing pattern of incidental catch in the salmon fishery, instead of opening a directed fishery prior to the salmon opening. However, in 1984 and 1985, harvest was allowed with large mesh (9-inch) nets from July to early August, with the goal of protecting chinook dip-in stocks. Catches are not yet available, but it appears that in the 1985 fishery the largest part of the sturgeon catch was caught in this fishery.

Other species are of little actual commercial value. Starry flounder appear so scarce that a directed fishery would probably not be practical. The dogfish fishery was discontinued because of lack of consumer demand.

All lands potentially usable for oyster beds have been claimed. About 75% of the intertidal lands, or about 32,000 acres, are privately held. About 30 firms have oyster tracts, with 90% of the tracts in the hands of the four largest firms. The rest of the intertidal area, consisting of about 10,000 acres, is called the "Oyster Reserves", is owned by the State of Washington and is administered by the Washington State Department of Fisheries (WDF). The State leases some of this land out to private growers. Some of the non-leased land is used for production of seed. The State collects and sells some of the seed itself, and also allows private firms to collect seed there.

Not all the potentially usable area is cultivated (Figure 21). About 10,000 acres have been cultivated in recent years (Washington State Department of Fisheries and Washington State Department of Ecology (DOE) 1985). About 2,500 acres of this area are usually devoted to fattening. Only 800 to 1,000 acres are harvested in a given year (Cheney, personal communication).

Oysters are harvested from September through May, with largest harvests occurring in early spring. During the summer months spawning reduces the quality below marketable standards.

3. Production Trends

Production has declined from 10 to 11 million pounds in the 1950's to 2 to 3 million in recent years (Figures 22 and 23). Production has partially recovered since the middle 1970's but the last two years' harvests have been relatively low. The primary factors responsible for the long-term decline and subsequent partial reovery are economic, but biological conditions also contribute to the variability.

a. Economic Factors

Lack of market penetration, increasing competition from abroad, and increasing price of imported seed have tended to depress production (Westley, 1985). For these reasons the grounds are not now used to capacity. The lack of market penetration may be due to the Willapa growers' failure or inability to make consistent contact with the large markets of the East coast and California (Cheney, personal communication).

Increasing competition from abroad is shown by the increase in imported oyster meat from about 12 million pounds in 1969 to about 27 million in 1984 (Westley, 1985). The major suppliers are Korea and Taiwan.

The price of imported Japanese seed increased from about $16 a case in 1969 to $60 in 1983 (Westley, 1985). As a result there has been greater reliance on Washington seed in recent years. Imports of Japanese seed declined from about 34,000 cases in 1969 to 600 cases in 1983. However, some reliance on imported seed may still be necessary because the Washington set is fully adequate only about 70% of the time.

Steadily increasing prices to Washington growers have tended to maintain some production even during periods when overall production was declining. Prices have been steadily increasing from about $7 per gallon in 1969 to about $19 a gallon in 1984. Recent increases in the market for halfshell oysters among local consumers (Cheney, personal communication) may account for at least a part of the recent recovery.

b. Biological Factors

Commercial production depends on continuing chemical control of burrowing shrimp, which would otherwise make the beds unsuitable for oysters. Other biological factors are less controllable. Heavy adult mortality occurrs in some years due in part to certain environmental conditions. Prediction of these conditions is possible but current management techniques can save only a part of the production. Reduced fattening in some years has been attributed to cyclical changes in ocean currents. The amount of natural set may be above or below the optimum level due to combinations of temperatures and prevailing winds. The impact of development is of lesser importance in Willapa Bay at present. The primary historical impact on oyster culture has been siltation of the beds, but this has not been a major problem in recent years. Each of these concerns is described in detail below.

Burrowing Shrimp. The burrowing shrimp of economic concern in Willapa Bay consist of two species, the ghost shrimp, also known as sand shrimp (*Callianassa californiensis*) and the mud shrimp (*Upogebia pugettensis*). Of the two, the ghost shrimp is considered more damaging due to its greater preference for bottom types that support oyster culture.

Ghost shrimp harm oyster production in two ways. The shrimp cast up tailings from their burrows and thus smother the smaller oysters. The burrowing also softens the sand, causing larger oysters to sink into the bottom. This softening also makes it hard for off-bottom culture using stakes to support oysters grown on ropes or in racks.

Ghost and mud shrimp have probably always been present in Willapa Bay. Their abundance becomes an economic problem when densities exceed about 10 burrows per square yard. High densities in certain years appear to result from peiodic disturbances in ocean currents known as El Nino. This results in unusually high water temperatures in Willapa Bay that stimulate reproduction of the shrimp. This has occurred in 1958, 1962, and 1982. Temporarily high abundance of ghost shrimp in such years results in high enough abundance in the following years to be of continuing economic concern. Practically all areas of the bay have been affected strongly enough to require spraying at one time or another (Figure 21).

Control has consisted of spraying with the insecticide Sevin (WDF and DOE, 1985). Spraying has been done annually since the 1950's, in virtually all parts of the Willapa tidelands (Figure 24). Application is limited to 300 acres a year to minimize the environmental impact. On a given tract, no repetition is allowed for six years.

Spraying has controlled ghost shrimp sufficiently to sustain commercial production. However, some part of the bay must be treated each year because Sevin has a short life (approximately three weeks) in the sediments and because the total area to be sprayed each year is limited. More effective control would probably allow more economical production (Shotwell, personal communication).

The primary adverse impact of spraying has been mortality of juvenile crab following spraying. Potential damage to the salmonid fisheries and to bird life may also result because Sevin is toxic to the small bottom-dwelling crustaceans (amphipods and copepods) upon which they feed. Continued controversy regarding these and other environmental issues could eventually affect the level of production.

Despite these drawbacks, WDF and DOE (1985) believe that no other alternatives appear capable of maintaining oyster production without greater environmental damage. Other insecticides that have been sufficiently studied are more persistently toxic in the environment than Sevin. Changing to raft or longline culture is not practical to the extent needed to eliminate the need for spraying. Harvest of the shrimp themselves for sport fishing bait has been proposed. However, questionable market conditions (Ferjancic et al., 1981) and low density for commercial harvest (Westley, personal communication) make this alternative doubtful.

<u>Adult Summer Mortality Syndrome</u>. Heavy adult mortality occurred in some years during the 1950's and early 1960's, and again may be on the increase (Scholz et al., 1984). Mortalities generally occurred when high water temperatures stimulated spawning over a prolonged period. Juveniles were not affected. Certain beds have shown to be more susceptible than others. Also, certain combinations of seed source and growing location may be more susceptible than others. The causative agent has not been clearly identified. Therefore, the options for management are to (1) remove oysters from dangerous areas before heavy mortality is expected, (2) harvest a year earlier than usual, or (3) change the seed source.

<u>Oceanic Conditions</u>. The El Nino phenomenon has been linked to reduced fattening of oysters. This apparently occurrs as a result of reduced upwelling of nutrient-rich water.

Consequently, primary productivity is reduced, and the oysters have a less abundant food resource.

Extent of Setting. Both scarcity and overabundance of natural set can be detrimental to production. Scarcity of natural set in Hood Canal and Willapa Bay can limit production. This is caused by a combination of unsuitable temperatures and wind conditions around the time of spawning.

Excessive set of wild oysters may also adversely affect production; in years of very high natural set, very high densities of unmarketable oysters resulted (Hedgpeth and Obrebsky, 1981). These authors recommended removal of unmarketable oysters to avoid competition for food with cultured oysters. However, Shotwell (personal communication) believes that every 3-5 years large natural set has been occurring but has not been affecting oyster fatness.

Sedimentation. Sedimentation can be defined as smothering of oysters with silt. This may occur from river inflow or from dredging. Regarding siltation from river input, Ferjancic et al. (1981) mentioned the loss of 2,000 acres of bed lands from 1959-70, presumably due to accelerated erosion from logging. Less impact is expected now due to reduced logging effort.

Dredging was formerly done by the Corps of Engineers to maintain the shipping channel in the Willapa River. This was discontinued in 1977 but dredging on a smaller scale for a small boat marina is under consideration. No conflict with the oyster industry is expected, in the view of Westley (personal communication), who believes environmental safeguards during dredging and spoil disposal are now adequate. Further, growers have not complained of excessive silt during previous dredging operations.

Pollution. Potential impacts which reduce the oxygen level in the water could occur from agriculture, and from sewage treatment plants in Raymond and South Bend. Septic systems could be a threat to water quality in the event of increased shoreline development (Ferjancic et al., 1981). The critical area is the north end of the Long Beach Peninsula.

4. Potential for Expansion

Production of up to 60 million pounds per year has been suggested but not clearly supported (Hedgpeth and Obrebsky, 1981). For the oyster industry in general, several things will have to happen before significant increases in production occur, according to Shotwell (personal communication). Marketing is considered the most important factor that must improve, but this is difficult with a seasonal product. Another factor is automation of processing, especially of the shucking process. Automation may be as important as improved culture techniques. Another desirable advance would be more effective reduction of ghost shrimp.

The potential land area for expansion of oyster beds at least to its former capacity exists, but the degree to which this will occur is debatable. A negative indication is the claim by some growers that the best growing lands are already being used, and that all fattening grounds are already being fully used.

One current trend that bodes well for expanding bed culture is the continuing local increase in demand for oysters on the halfshell. This type of oyster does not need to be as large as the traditional shucked market requires, so marginal lands that would not produce oysters large enough for the shucked market might be used. The high price encourages further development.

Off-bottom culture has been proposed as a means of expanding economical production but its potential is difficult to assess. The advantages are greatly reduced mortality, greatly increased growth, and better fattening (Ferjancic et al., 1981). The disadvantages are higher cost for labor and equipment, greater susceptibility to fouling, and conflicts over use of water areas. In particular, the use of State-administered lands now in reserve may require legal changes before off-bottom culture is possible. All subtidal lands are owned by the State of Washington and managed as public lands by the Washington Department of Natural Resources (DNR).

Certain types of off-bottom culture appear more promising than others (Westley, personal communication). Willapa Bay is best suited to intertidal off-bottom culture because of its limited subtidal area. Structures supported on the bottom are preferred to those floating on the surface because of strong tidal currents and wave action. Racks with mesh bags are considered the best method (Shotwell, personal communication). Culture on stakes with shell strung between them (that is, staked longlines) have been criticized because large, unmarketable clusters of oysters sometimes result. However, clustering has not been a significant problem in some staked longline operations in Willapa Bay (Cheney, personal communication).

B. Crab

Dungeness crab (Cancer magister) is second to oysters in commercial importance in Willapa Bay. The period of 1980-1984 had an average harvest of 397,000 pounds (Ward and Hoines, 1985). This is about 6% of the Washington total.

1. Source of Production

Harvest depends entirely on natural production. Reproduction occurrs outside the bay, but Willapa Bay provides some rearing area.

2. Distribution

Harvest is mainly offshore (Figure 25) but some fishing also occurrs in the bay. The stock probably occupies the area from the Columbia River to Grays Harbor. (Westley, personal communication).

The fishery within the bay operates near the mouth of the bay in the deeper channels down to depths of 60 feet (WDF and DOE, 1985). The season is usually from January to August (Proctor et al., 1980). The opening date is set to overcome handling mortality that would result to undersized crabs caught too soon after moulting. Timing of completion of the moult is determined by a test fishery. Most of the harvest is taken in the early part of the season, with the first 45 days usually taking 60% of harvest.

3. Production Trends

Production trends are shown in Figures 26 and 27. Catch is considered closely related to annual abundance (Westley, personal communication), which is cyclical, having a period of 7 to 13 years. Factors responsible for this include variation in oceanic factors which affect survival of crab larvae (Proctor et al., 1980) . One such factor is the El Nino phenomenon. The occurrence of warm surface waters limits the normal summer upwelling of nutrient-rich water off the Washington coast. This diminishes the productivity in Willapa Bay and offshore. Monthly indexes of the extent of upwelling have been correlated with juvenile crab abundance 6 months to 1.5 years later.

Changes in the longshore currents from one year to another may affect the extent of migration of crabs into Willapa Bay. The Columbia River plume is the main influence on bay water composition in winter months (Figure 28). Its strength may vary depending on annual runoff. The importance of estuarine rearing areas is not well understood because some individuals rear entirely offshore. Changes in annual rainfall in the watershed and resulting changes in salinity of estuary rearing areas may affect survival to adulthood. Annual variation in temperature and abundance of predators in the rearing areas may also be factors.

4. Management strategy

Management is based on allowing adult crabs one or more reproductive seasons before harvest. For this reason the minimum size limit (6 1/4 inches) is well above the reproductive size (4 inches). There are no year to year changes in regulations, no predictions of harvest, and no in-season updates because of the lack of biological information to predict annual recruitment to the fishable stock.

5. Potential for Increased Harvest

The sources we consulted (Proctor et al., 1980 and Westley, personal communication) believed that virtually all the available harvest is now probably being taken. Westley believed the fishery was overcapitalized, and that no new effort was desirable. No contribution from artificial production is likely to change this situation in the foreseeable future.

C. Clams

Clams are at present the least important commercial shellfish resource of Willapa Bay. Over the 1980-84 period 33,000 pounds were harvested (Ward and Hoines, 1985). This was about 1% of the statewide total for the period. The principal species of concern is the introduced Manila clam (Tapes japonica), also known as the Japanese littleneck. Other species of lesser economic value are eastern softshell clam (Mya arenaria), cockle (Clinocardium nuttalli), horse clam (Tresus nuttalli), native littleneck (Protothaca staminea), and butter clam (Saxidomus giganteus).

1. Source of Production

The harvest at present depends entirely on natural production. There is no record of artificial seeding.

2. Distribution

Harvest occurrs in the gravelly intertidal zone in highly scattered areas within Willapa Bay (Ferjancic et al., 1981). Manila clam and cockle habitat includes oyster beds but these species of clam are not harvested except from a few intertidal beds at Long Island. Eastern softshell clams are very widely distributed in the intertidal zone. Butter clams are concentrated in one south bay subtidal location and are not now utilized. We did not locate information on the distribution of horse clams and native littlenecks.

3. Production trends

Ferjancic et al. (1981) attributed decrease in production since the 1950's to overharvest while Cheney (personal communication) attributed the decline to decreased harvest effort. Production trends are shown in Figure 29.

4. Potential for Increased Harvest

Potential may exist for a modest increase in production. Approximately 2,000 acres are now suitable for hardshell clam production (Ferjancic et al., 1981). This includes marginal oyster grounds. Cheney (personal communication) believes this estimate must include Eastern softshell grounds, which represent a softer habitat than that which is suitable for other clam species. Ferjancic et al. (1981) suggested that the beds around Long Island would give higher harvest of Manila clams if they were plowed to increase aeration.

Artificial enhancement of production would at the minimum require addition of gravel and possibly shell to areas to be used primarily as clam beds (Hedgpeth and Obrebsky, 1981). We believe this would require extensive environmental evaluation and review. Ferjancic et al. (1981) suggested that artificially-produced manila clam seed could be used to reseed the grounds.

D. Currently Unutilized Species

1. Scallop

Scallops have moderate potential for culture in Willapa Bay. They have the advantages of fast growth and high price. Several new developments may make culture more economical in the near future. Seed supply of four native species has recently been collected (Bettinger, personal communication). Good set was achieved with pink scallop (*Chlamys rubida*) and spiny scallop (*C. hastata hericia*). Moderate set was obtained with rock scallop (*Hinnites multirugosus*) and weathervane scallop (*Patinopecten caurinus*).

Growing techniques have recently been developed to avoid many of the problems normally faced in off-bottom culture in subtidal areas. Effects of wave action, currents, and boat traffic may be overcome to a greater extent using new techniques for anchoring sets of longlines (Mottet, 1978).

Other developments with rock scallop (Olson, 1983 and Bronson et al., 1984) point to the practicality of culturing this species. Rock scallops were relatively easy to culture to a length of 2-4mm in a hatchery. Intermediate culture was succesful in nets, boxes, or bags. Ferjancic et al. (1981) suggested that this species would be best cultivated from rafts on hanging ropes, but Bettinger (personal communication) recommends mesh bags. Growth was good in all marine areas tested, including one site in Willapa Bay. Scallops were grown subtidally on racks supported from the bottom. Survival was good throughout the summer. However, heavy winter mortality occurred, apparently due to unusually low temperatures and unusually high freshwater runoff.

A positive element for certain scallop species is the developing market for steamer scallops as an alternative to scallop meat. This is due to changing consumer tastes. Pink and spiny scallops are best for this purpose, because of their ease of culture when relatively small size is sufficient. On the other hand, rock and weathervane scallops are best for the traditional market in which only the large adductor muscle is marketed.

Non-native species have been recommended by Ferjancic et al. (1981) but may have problems in becoming certified for introduction due to disease or other environmental issues. These species are bay scallop (Aequipecten irradians) from the east coast and sea scallop (Patinopecten yessoensis) from Japan.

Potential development in Willapa Bay is limited by a shortage of required habitat. On-bottom culture requires subtidal sand or rock, depending on the species. Off-bottom culture needs either bottom support (rack culture) and harvest by divers, or suspended culture (longlines or rafts) over subtidal areas. The difficulty with rafts is the same as that affecting oyster culture. Another problem is low tolerance to reduced salinity. Salinities must be greater than 15 parts per thousand, but borderline conditions occur in some parts of Willapa Bay.

2. Abalone

The native pinto abalone (Haliotis kamtschatkana) has been considered for culture . Abalone has the desirable traits of high demand and price. However, Olson (1983) has presented several general reasons why this species may not be suitable for culture at this time. Growth is very slow, and as a result culture operations would have to compete with wild-caught abalone from existing fisheries in Alaska and British Columbia. Furthermore, the cost of seed production and tank rearing is very high. Finally, the degree of recovery from planting in the wild is not well known.

Willapa Bay has little or no suitable habitat for this species. There is a lack of rocky subtidal areas required for natural production. There is also a lack of subtidal areas suitable for diking, if a more protected culture site were desired.

3. Mussels

Mussels (Mytilus spp) have also been considered for commercial cultivation. Mussels have moderate commercial value and can grow on intertidal ropes on stakes, like oysters (Cheney, personal communication). However, oystermen view mussel culture in Willapa as a source of competition with off-bottom oyster culture. This is because mussels tend to set heavily on off-bottom structures and could foul the oysters. Commercial potential is further brought into question by uncertain market conditions, and rapid deterioration during shipping.

4. Pink shrimp

The pink shrimp (Pandalus jordani) has been suggested as a candidate for a fishery within Willapa Bay (Hedgpeth and Obrebsky, 1981). This species was caught in Willapa during a few years in the 1950's. The authors believed that an annual fishery could be maintained through improvements in harvest management.

One problem with this is that most of the population is concentrated in the deeper waters offshore (Figure 25). Another problem is that a trawl fishery inside Willapa would conflict with the drift gillnet fishery now operating for sturgeon and salmon, and later in the season would conflict with crab pots (Shotwell, personal communication).

Artificial production is not sufficiently developed at this time to supplement the catch or support commercial aquaculture (Ferjancic et al., 1981).

E. Potential Development of Tribal Land

Development of tribal land for shellfish culture depends on the quality of the substrate and the exposure to currents (Westley, personal communication). The shoreline in the area of Tokeland is subject to recurrent erosion and subsequent deposition over a 13 to 20 year cycle (U.S. Army Corps of Engineers quoted by Hedgpeth and Obrebsky, 1981). Our cursory observations in the field indicated the outer shore near the reservation was exposed to high currents and wave action, and the inner areas appeared heavily infested with burrowing shrimp. However, the area must be examined in more detail before a definitive statement can be made on suitable culture areas.

SUMMARY

1. Willapa Bay supports three species of salmon: fall chinook, coho, and chum. All steelhead returning to the bay are winter run (that is, return to the river occurs between November 1 and April 30).

2. Two fisheries operate within Willapa Bay and its tributaries: the non-Indian commercial fishery and the sport fishery. Most sport effort is directed toward steelhead. Sport salmon catch is low relative to the commercial catch. In the last several years the sport fishery caught 14% of the total catch of local chinook stock, 12% of the coho, and 3% of the chum.

3. Non-local chinook stocks entering Willapa Bay belong primarily to Columbia River hatchery runs. They are the earliest salmon to enter Willapa Bay, and are usually present from early July to mid-August. They are present principally in the waters of Willapa Bay closest to the ocean. These stocks are at present depleted and require protection from a directed fishery in Willapa Bay. Non-local chinook are still present in the first half of August when the local Willapa chinook run is also beginning to return. Consequently, the management goal is to protect the non-local stocks by opening the fishery after the non-local stocks have begun to leave the bay, and by restricting early harvest to the inner areas of the bay.

4. Local chinook are those produced in the Willapa Bay watershed, either in hatcheries (about 60% of the run) or naturally.

a. These runs begin to enter Willapa Bay in early August, becoming more numerous in the catch than non-local stocks by the third week of August.

b. Harvest of the local chinook runs in Willapa Bay has been limited to incidental catch in the fishery directed at coho and, in some years, also at chum. This limitation has the goal of providing sufficient broodstock for the expanding hatchery program. An annual combined escapement to the hatcheries of 9,000 adults is desired in the coming years to build the run to the hatcheries' full capacity.

c. Hatchery production is expected to increase enough to allow increased harvests within four years. The US/Canada treaty is expected to increase the terminal runs of Willapa Bay chinook, but to what degree is still unknown.

d. The distribution of the hatchery runs among the rivers tributary to Willapa Bay corresponds to the respective numbers of fingerlings released at the Willapa, Nemah, and Naselle Hatcheries. In recent years the Willapa Hatchery has contributed about 37% of the releases of larger fingerlings, the Nemah Hatchery 23%, and the Naselle Hatchery, 40%.

5. Management of Willapa Bay coho harvest has the goal of efficient harvest of the production from the three hatcheries in the Willapa Bay watershed. Hatchery fish make up about 90% of the Willapa Bay run.

a. Coho enter the fishery in the first week of September and peak catches generally occur in the first week of October.

b. Hatchery escapement has generally exceeded production goals, so directed fisheries have generally been allowed.

c. The distribution of adult coho in the vicinity of the three hatchery rivers is approximated by the percentages of respective smolt releases for recent years. These proportions were 23% from the Willapa Hatchery, 27% from the Nemah Hatchery, and 50% from the Naselle Hatchery.

d. A potential harvest conflict exists each year between local hatchery chinook and local hatchery coho. The hatchery chinook run has not always met the hatchery escapement goal. Because of the temporal overlap between chinook and coho, it has been necessary to restrict the coho fishery to the outer area of the bay. This has resulted in satisfactory hatchery escapement of chinook, but overescapement of coho.

6. Chum salmon harvest in Willapa Bay is managed to sustain optimum natural production in the tributaries of the bay. Hatchery fish make up a relatively small portion of the run.

a. Chum enter the fishery about the first week of October. A definite peak in the catch occurs between the third week of October and the first week of November.

b. Escapement goals have generally been met in recent years, so a targeted fishery is usually conducted for this species. There is an overlap between the chum and coho runs. For this reason, in some years all harvestable chum were taken incidentally to the coho fishery. In most years, however, both the hatchery coho and wild chum runs have been numerous enough to allow efficient harvest of both without falling short of either escapement goal.

7. Steelhead returning to the Willapa Bay tributaries are caught almost entirely in the river sport fishery. Smolts from hatcheries outside the Willapa watershed are planted into all the major Willapa Bay tributaries.

a. Regulations reflect management for harvest of hatchery-produced fish early in the season (December through February) and some degree of protection for the wild run later in the season.

b. The Willapa River contributes over half the catch, and the Naselle River about a quarter of the catch.

8. Sturgeon are harvested primarily as incidental catch in the early months of the commercial salmon fishery.

a. Green sturgeon catch since the early seventies has exhibited a definite decline that is closely paralleled by the catch per landing. Little is known about factors affecting the population of this species.

b. The white sturgeon population harvested in Willapa Bay is probably in stable condition. This is suggested by the absence of a declining trend in the Columbia River commercial catch per landing and a stable size structure of the sport catch there. Both catches are thought to represent the same reproducing population.

9. Culture of Pacific oysters dominates the shellfish production of Willapa Bay. Virtually all intertidal areas in oyster culture are owned by private firms or the State of Washington.

a. Continued production depends on annual spraying to control ghost shrimp. The continuing controversy over the environmental effects of this practice could eventually affect production.

b. Present economic conditions do not warrant full use of potential oysterlands. Potential for expansion depends largely on the effects of competition from imported oyster meats. Oysters might be made more competitive, and lands might be used more fully, if mechanical shucking became practical or if off-bottom culture were more fully developed.

c. The development of a local market for relatively small oysters on the halfshell should lead to modest expansion in the future. Such expansion could lead, in turn, to use of lands now considered marginal for growing larger oysters for shucking.

10. The Willapa Bay crab fishery is much less important economically than oyster culture. The resource is highly cyclical but is fully utilized. The existing fishery is considered to have more boats and gear than are needed for efficient harvest.

11. Commercial clam harvest makes up a very small part of the Willapa shellfish economy. Modest expansion might be possible if some areas were managed as clam beds and more gravel were brought in. However, habitat enhancement might require extensive evaluation of the environmental impact.

12. Culture of scallops is not now practiced in Willapa Bay but recent research suggests some potential. The extent of culture would be limited by the relative scarcity of sheltered subtidal areas.

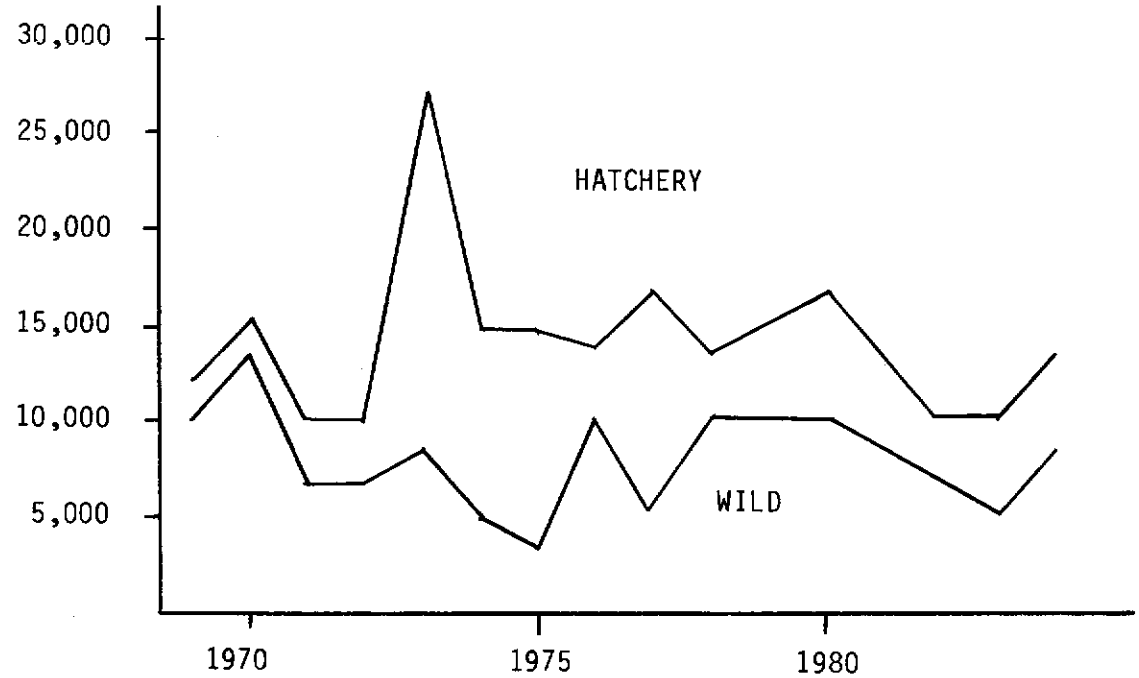

Figure 1. Annual hatchery and wild chinook run size. X-axis represents year of catch and Y-axis represents number of fish.

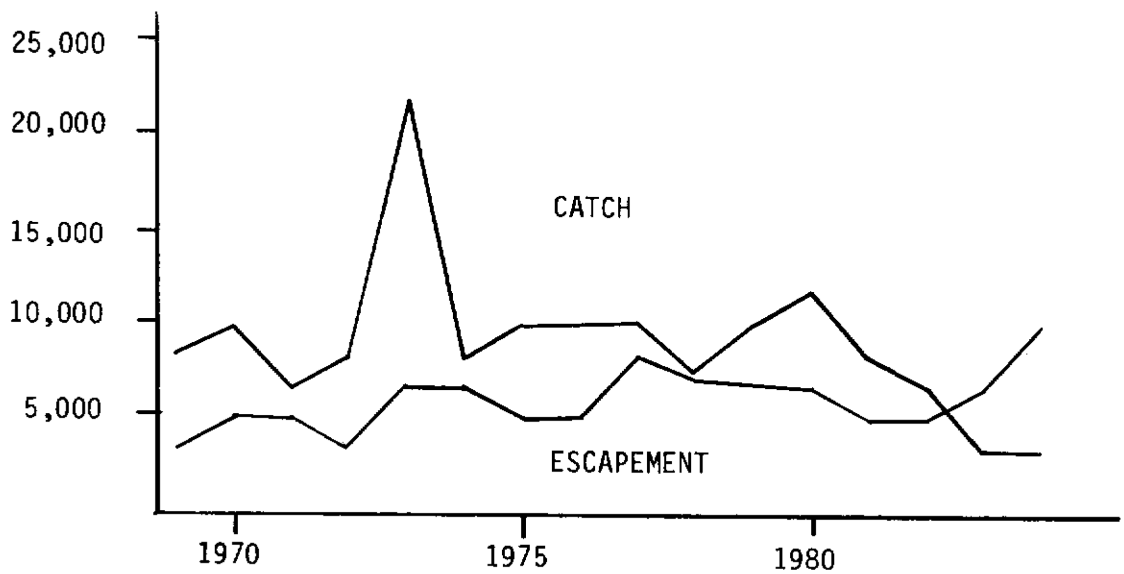

Figure 2. Annual hatchery-run chinook salmon catch and escapement. X-axis represents year of catch and Y-axis represents number of fish.

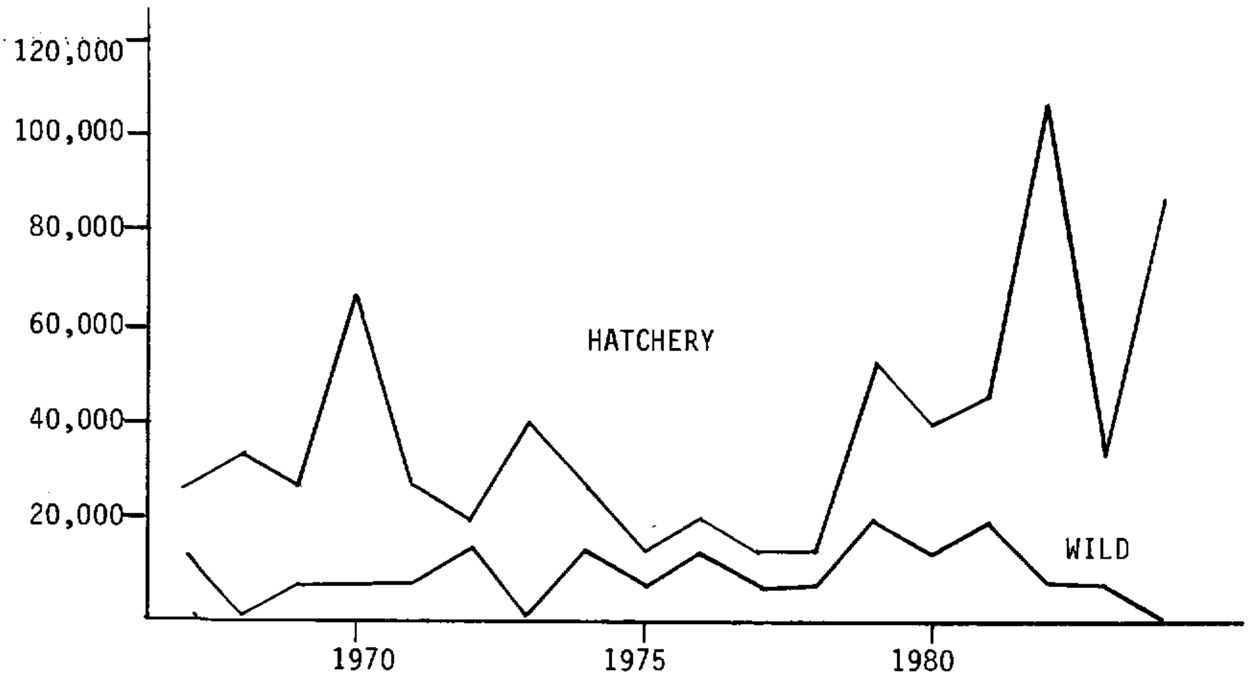

Figure 3. Annual hatchery and wild coho run size. X-axis represents year of catch and Y-axis represents number of fish.

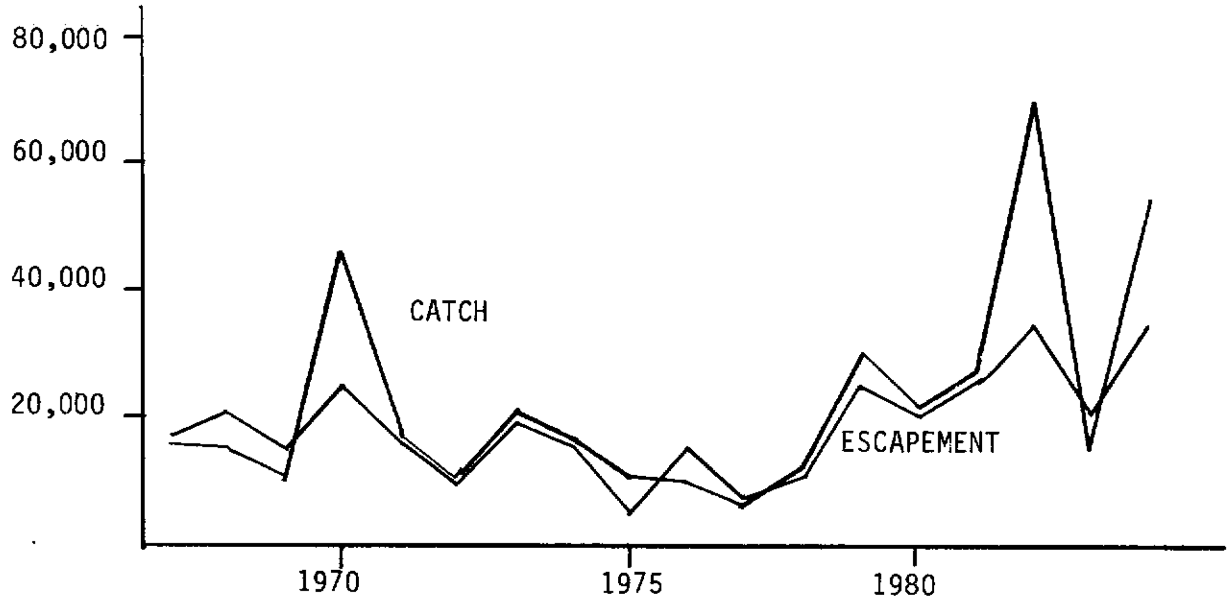

Figure 4. Annual hatchery run coho salmon catch and escapement. X-axis represents year of catch and Y-axis represents number of fish.

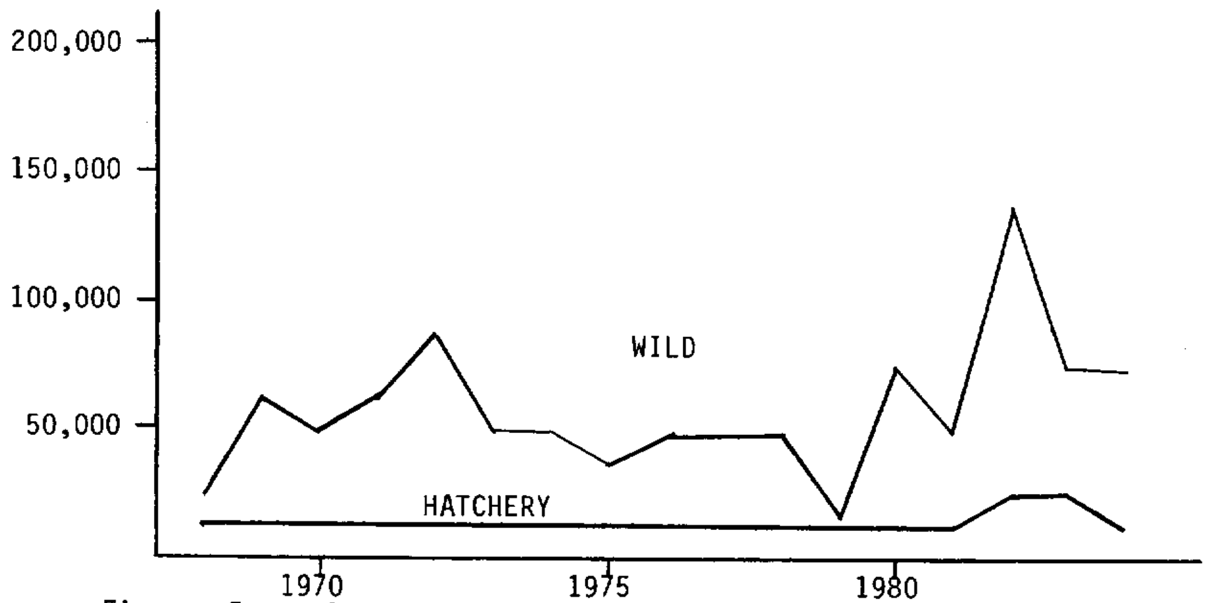

Figure 5. Annual hatchery and wild chum run size. X-axis represents year of catch and Y-axis represents number of fish.

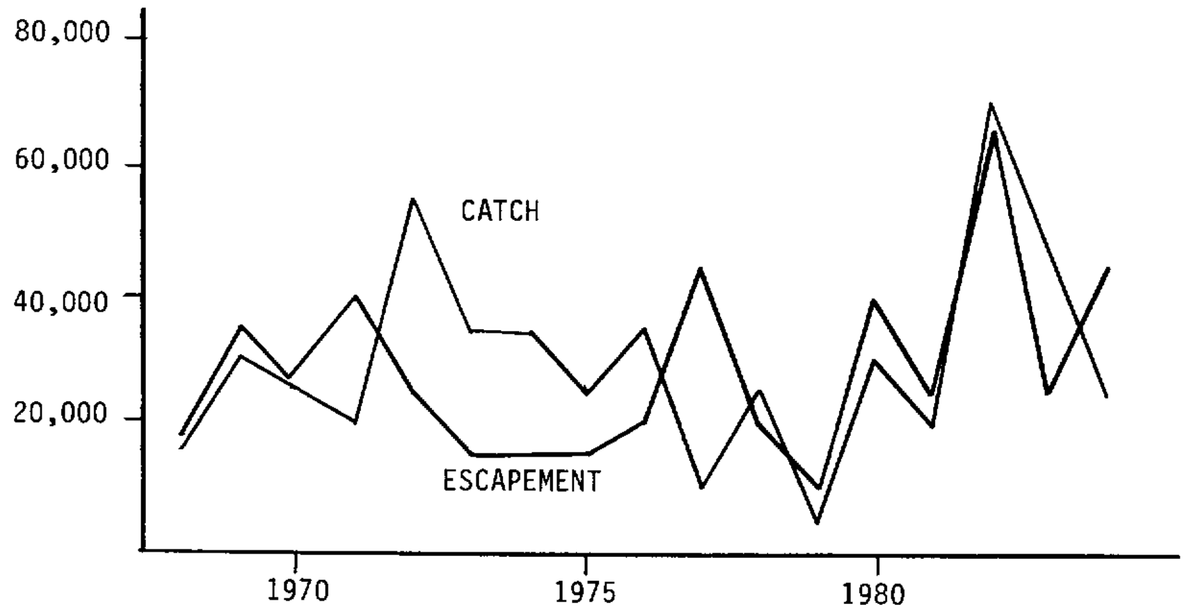

Figure 6. Annual wild chum salmon catch and escapement. X-axis represents year of catch and Y-axis represents number of fish.

Figure 7. Annual release of subyearling chinook. X-axis represents (broodyear + 4) and Y-axis represents thousands of fingerlings larger than 150/lb.

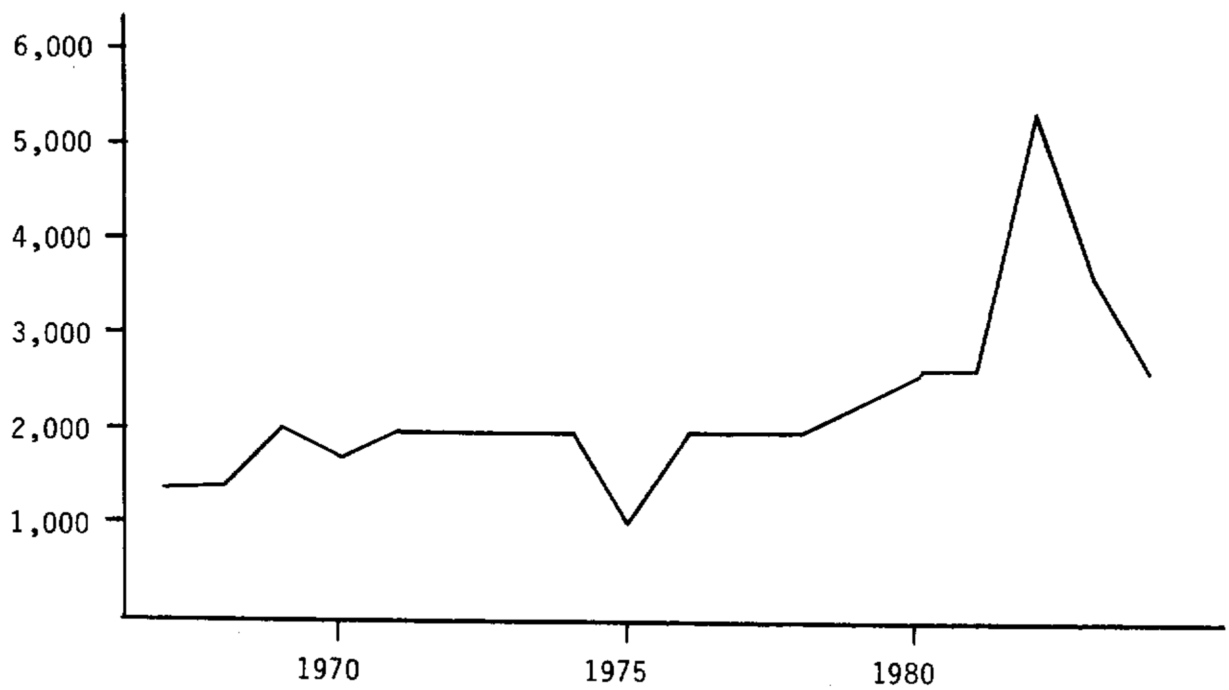

Figure 8. Annual release of yearling coho. X-axis represents (broodyear + 3) and Y-axis represents number of smolts X 1,000.

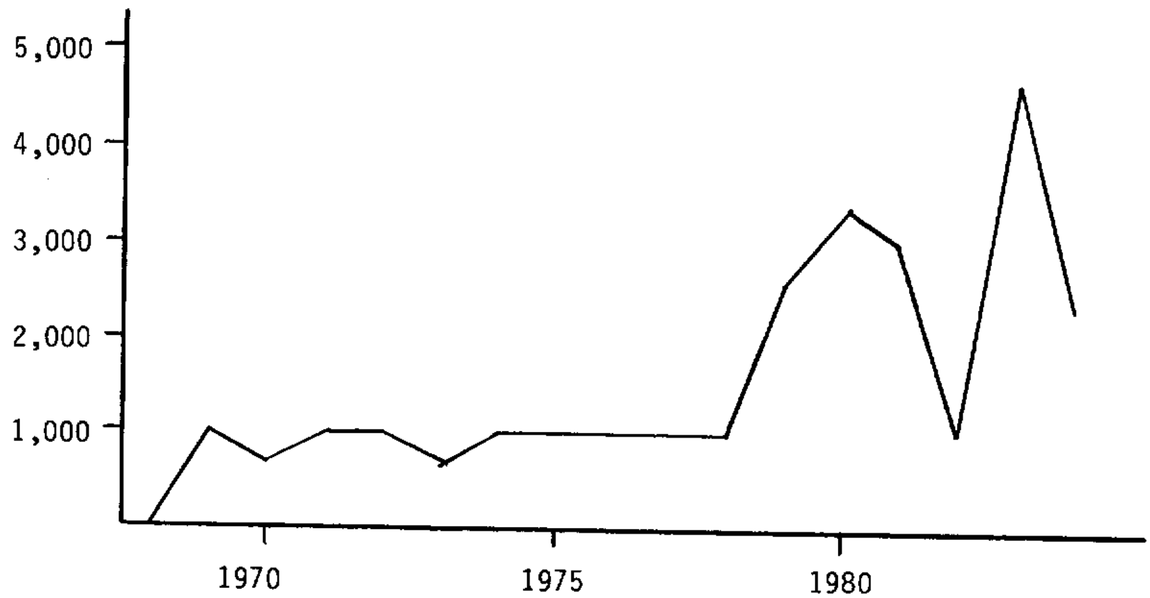

Figure 9. Annual release of chum fry. X-axis represents (broodyear + 3) and Y-axis represents number of fry X 1,000.

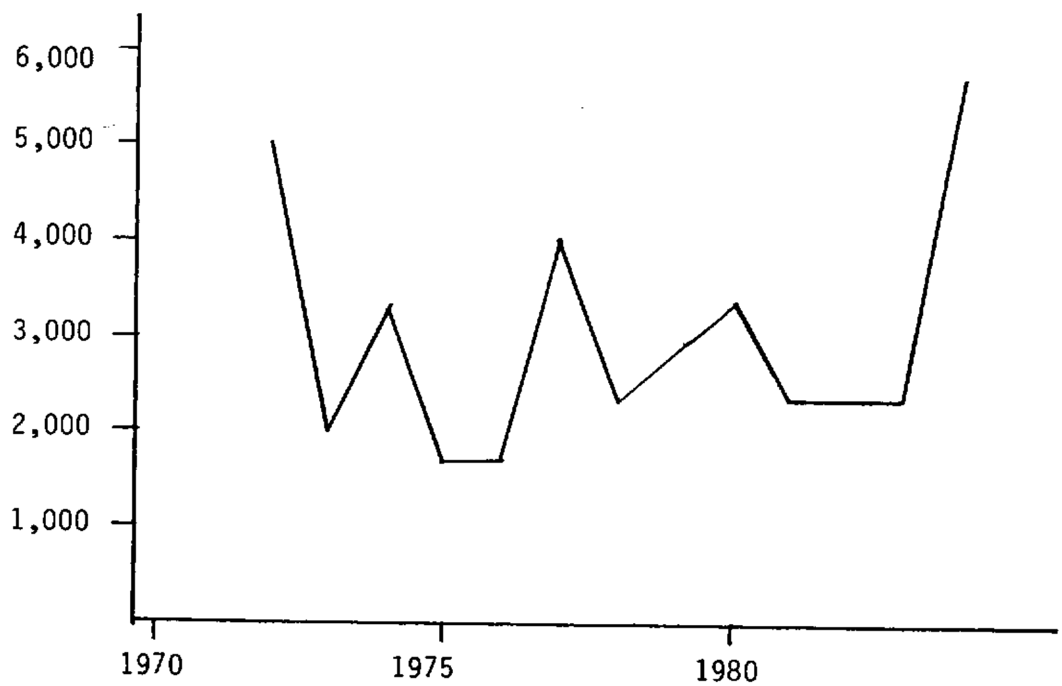

Figure 10. Annual sport catch of winter-run steelhead. X-axis represents season of catch (for example, 83 represents the 1983-84 season) and Y-axis represents number of fish kept by anglers.

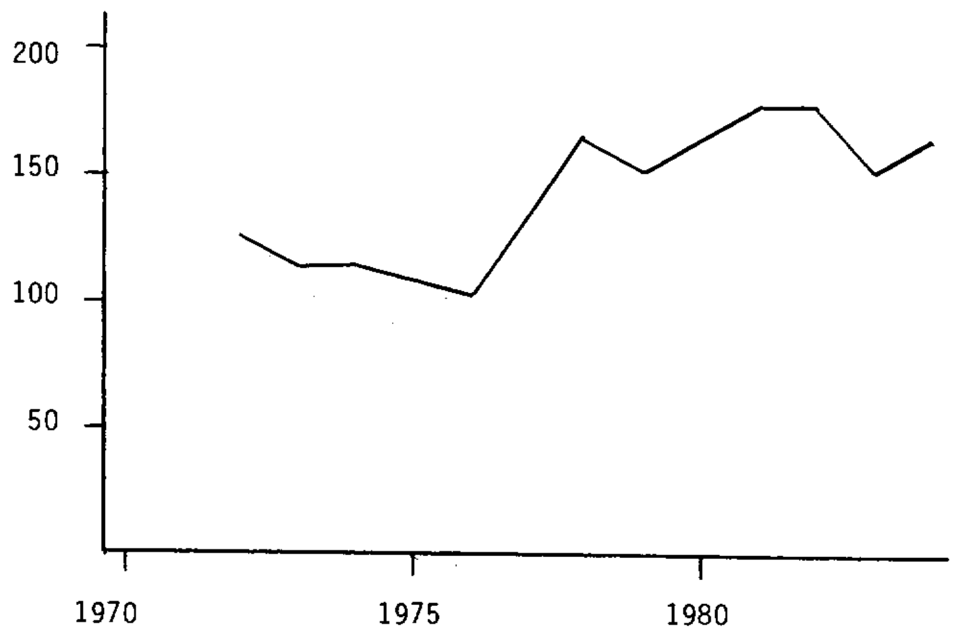

Figure 11. Annual releases of steelhead smolts. X-axis represents (broodyear + 3) and Y-axis represents number of smolts X 1,000.

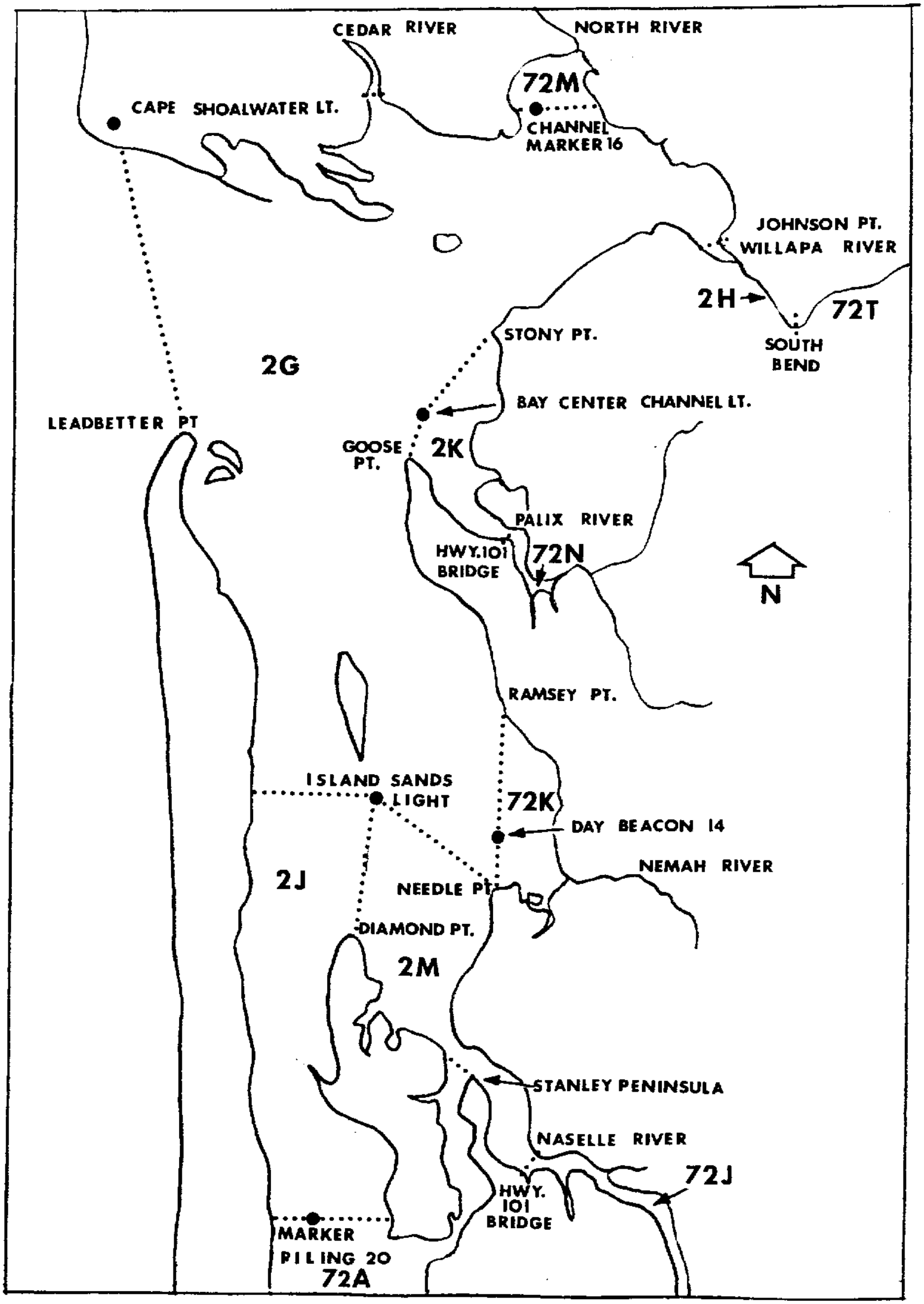

Figure 12. Willapa Bay, Washington, showing Washington Department of Fisheries catch reporting areas.

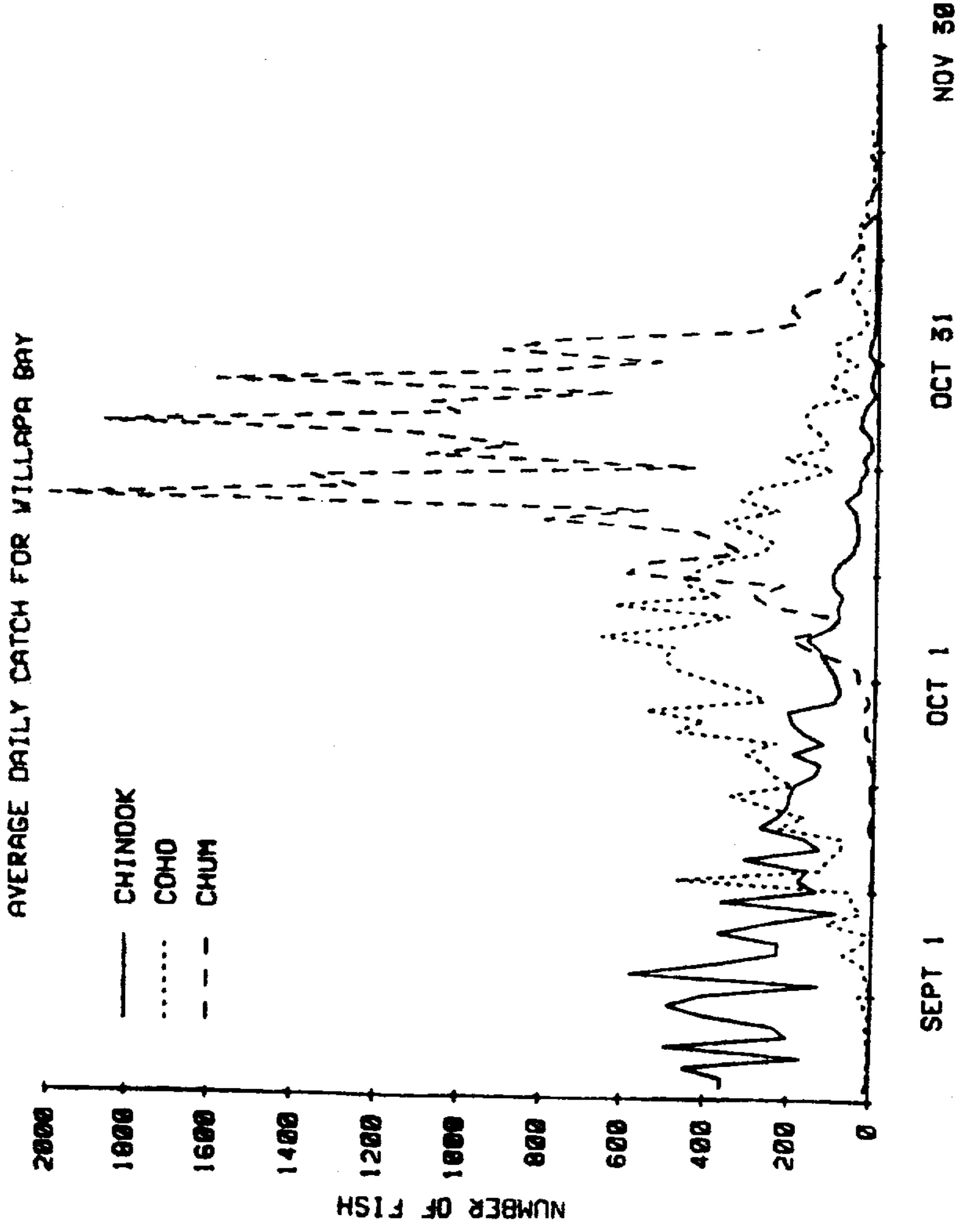

Figure 13. Timing of salmon catches in Willapa Bay.

Figure 14. Annual green sturgeon catch. X-axis represents year of catch and Y-axis represents pounds of fish.

Figure 15. Annual green sturgeon catch per landing. X-axis represents year of catch and Y-axis represents pounds per landing.

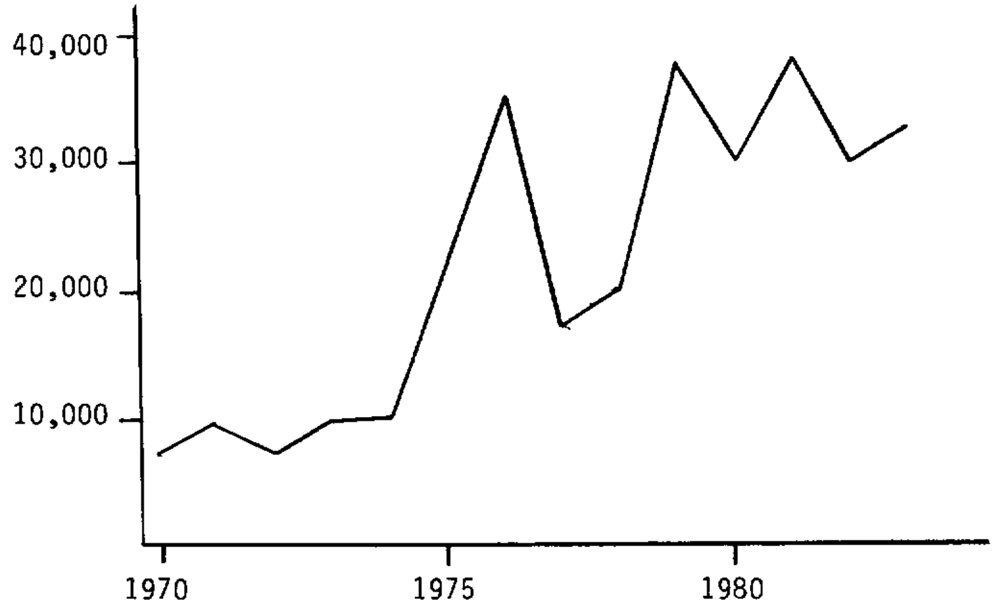

Figure 16. Annual white sturgeon catch. X-axis represents year of catch and Y-axis represents pounds of fish.

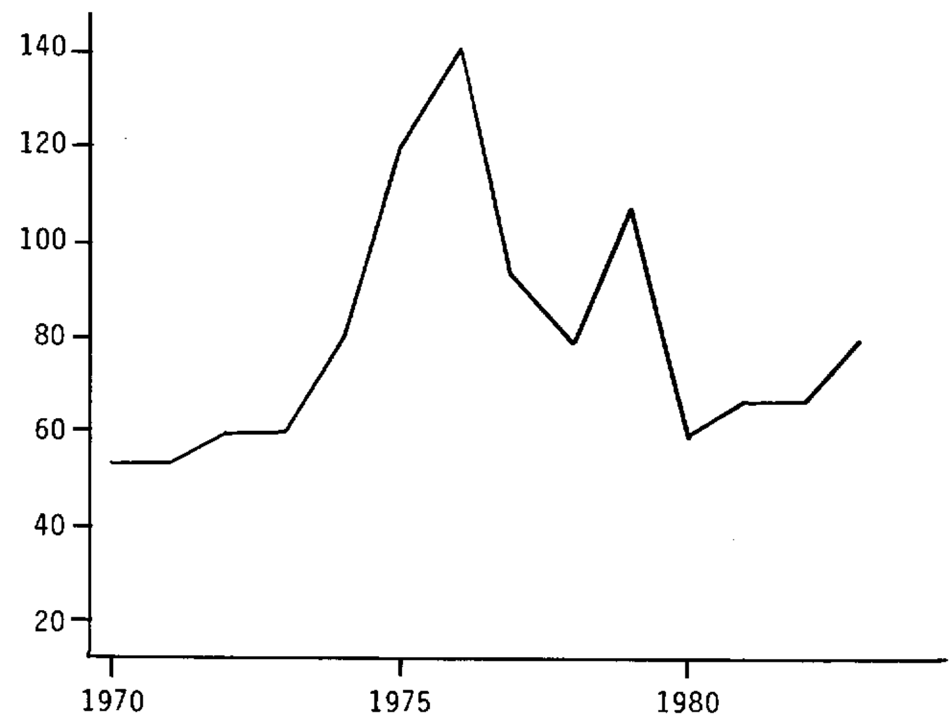

Figure 17. Annual white sturgeon catch per landing. X-axis represents year of catch and Y-axis represents pounds per landing.

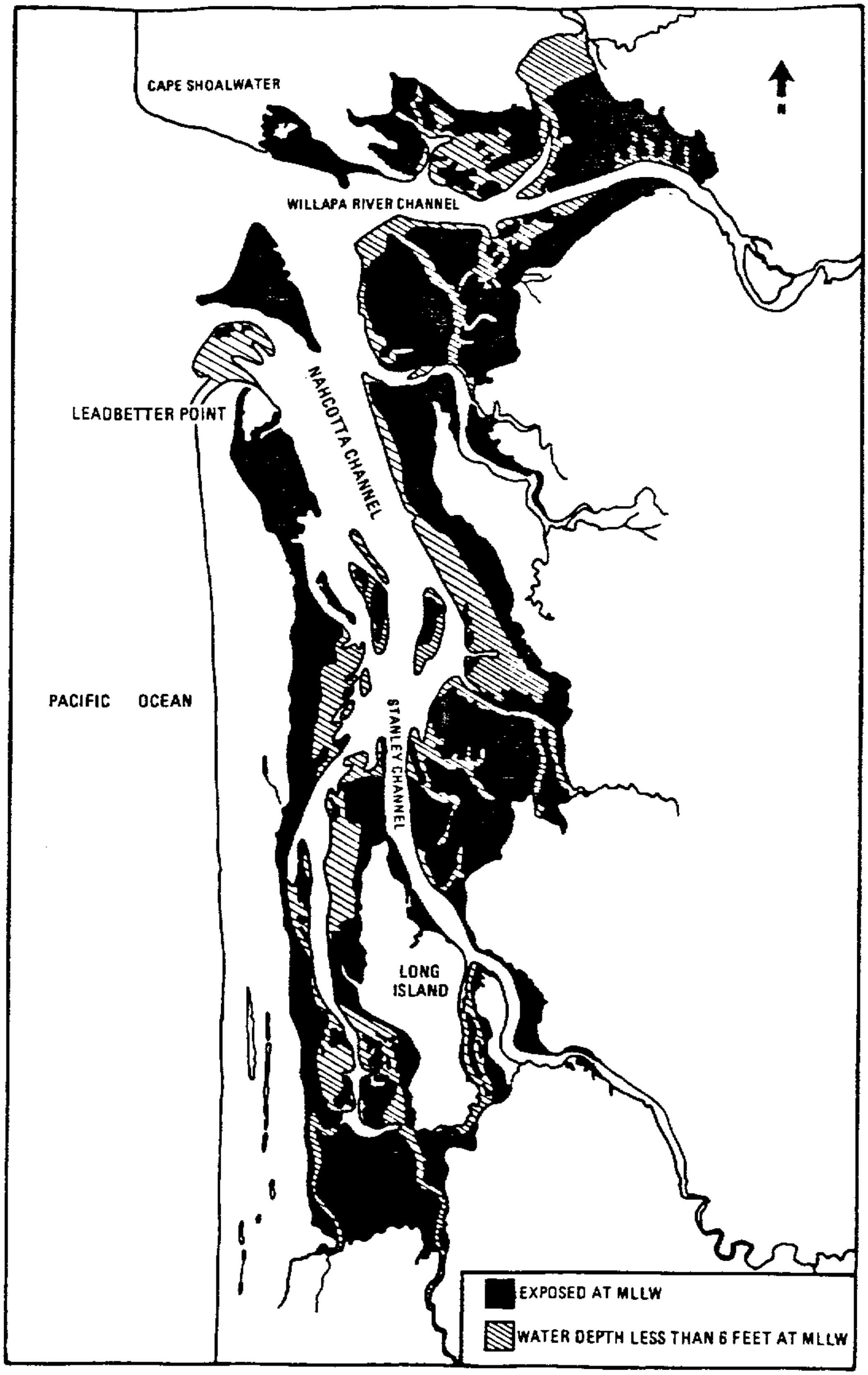

Figure 18. Channels and exposed tidelands of Willapa Bay (Shotwell, 1977 as reproduced in Hedgpeth and Obrebsky, 1981).

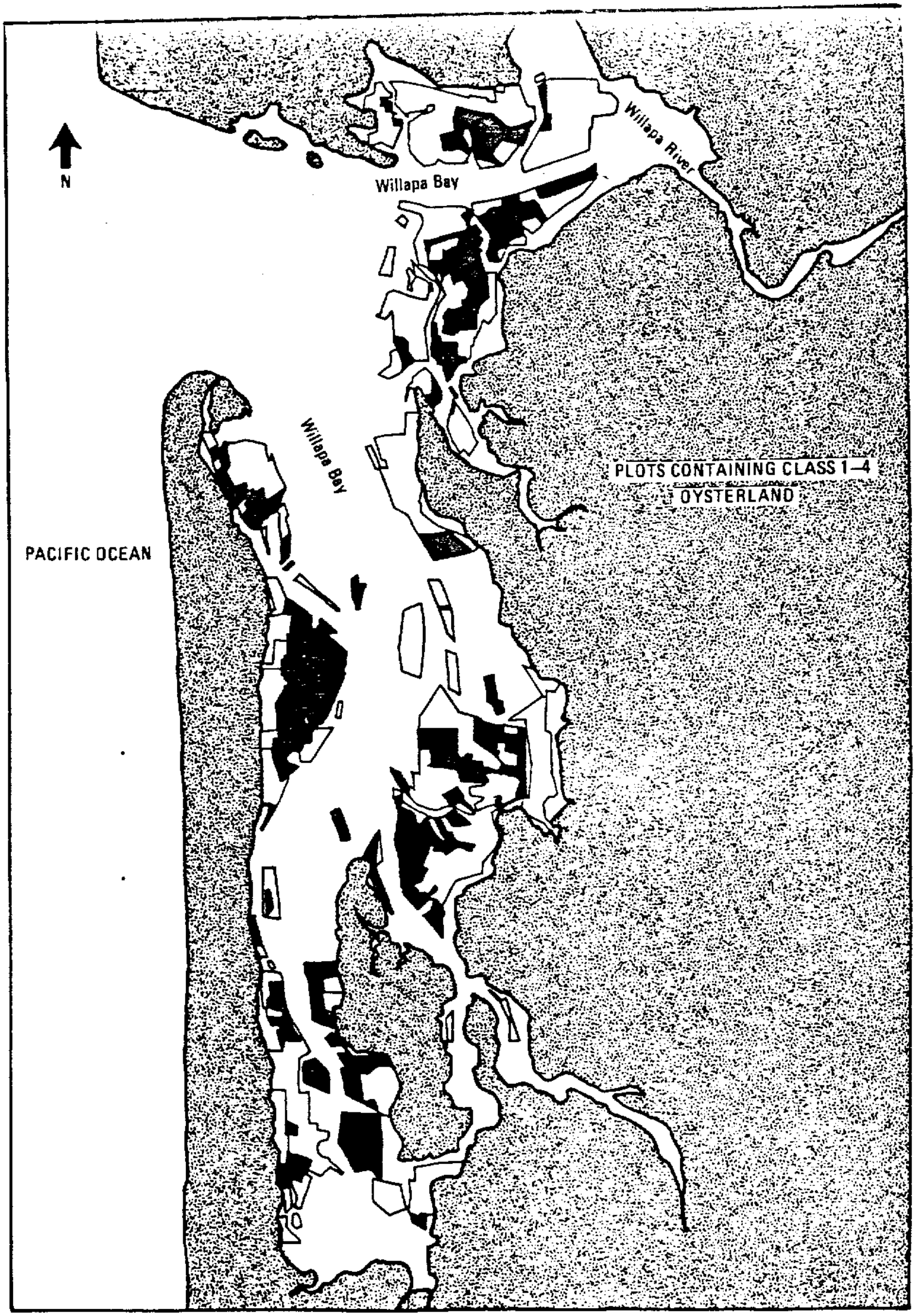

Figure 19. Productive oysterland (shown in black) in Willapa Bay (Shotwell, 1977 as reproduced in Hedgpeth and Obrebsky, 1981). Lines denote boundaries of land claimed for oyster culture.

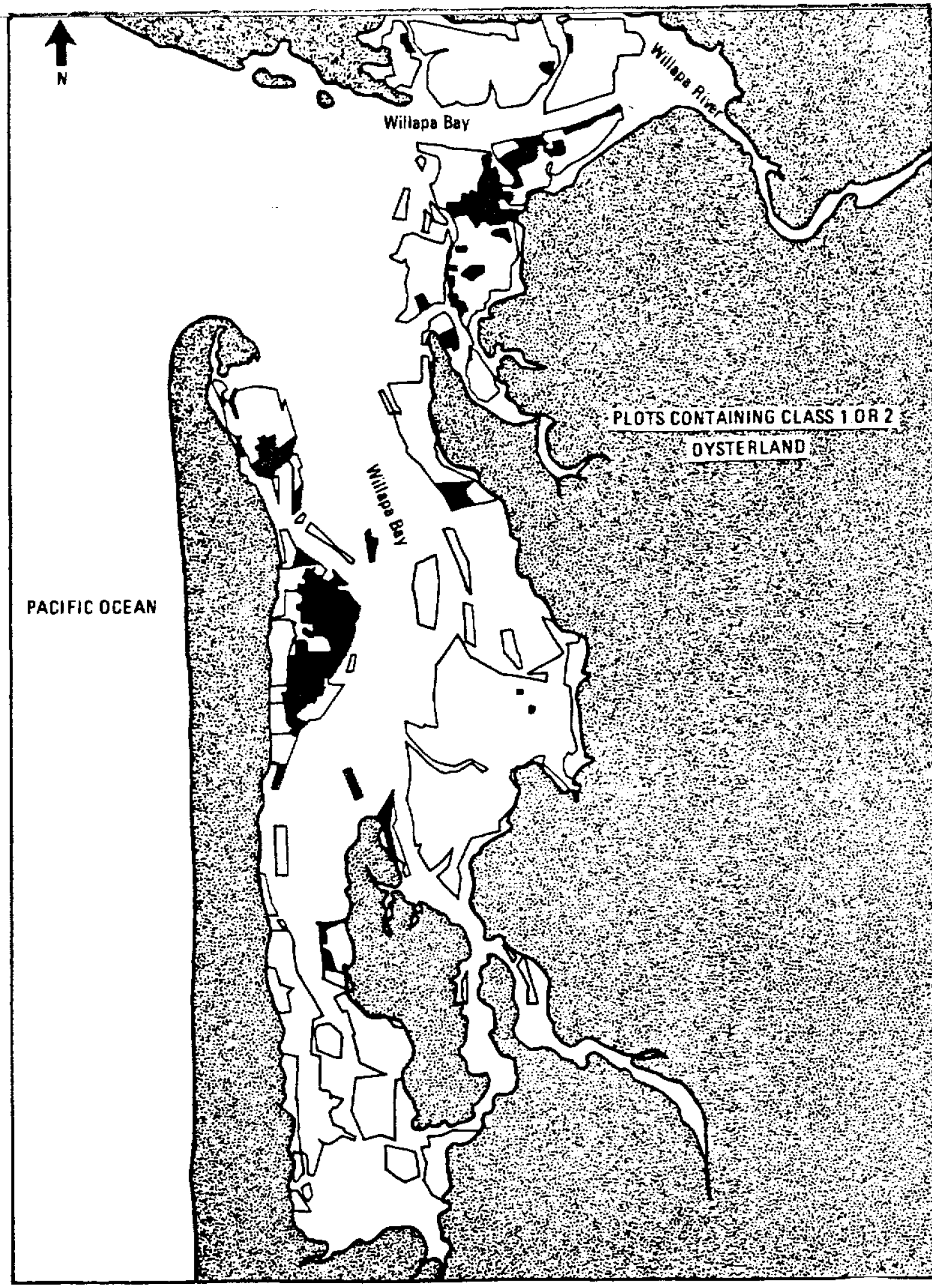

Figure 20. Oyster fattening land (shown in black) in Willapa Bay (Shotwell, 1977, as reproduced in Hedgpeth and Obrebsky, 1981). Lines denote boundaries of land claimed for oyster culture.

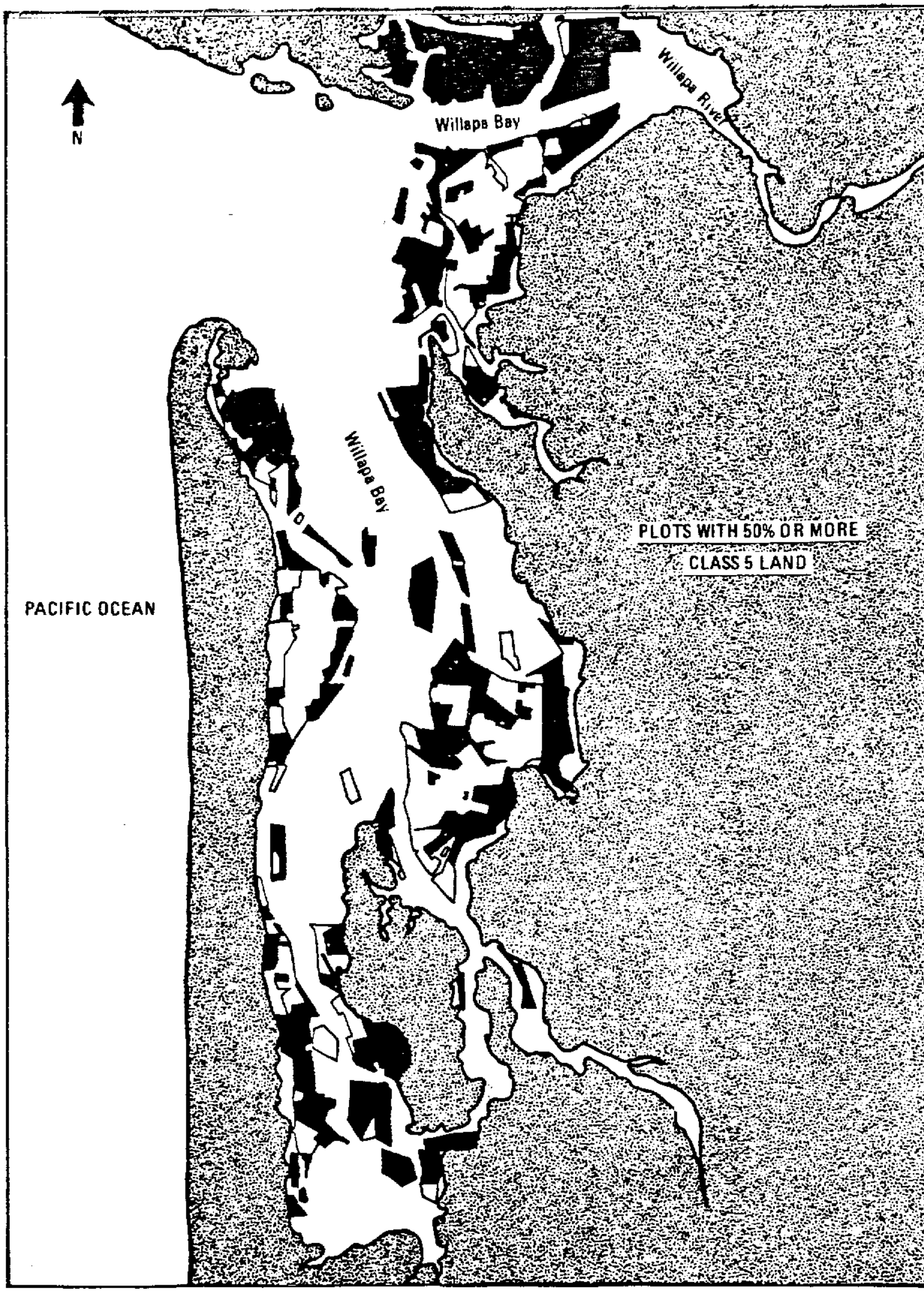

Figure 21. Non-productive oysterland (shown in black) in Willapa Bay (Shotwell, 1977, as reproduced in Hedgpeth and Obrebsky, 1981). Lines denote boundaries of land claimed for oyster culture.

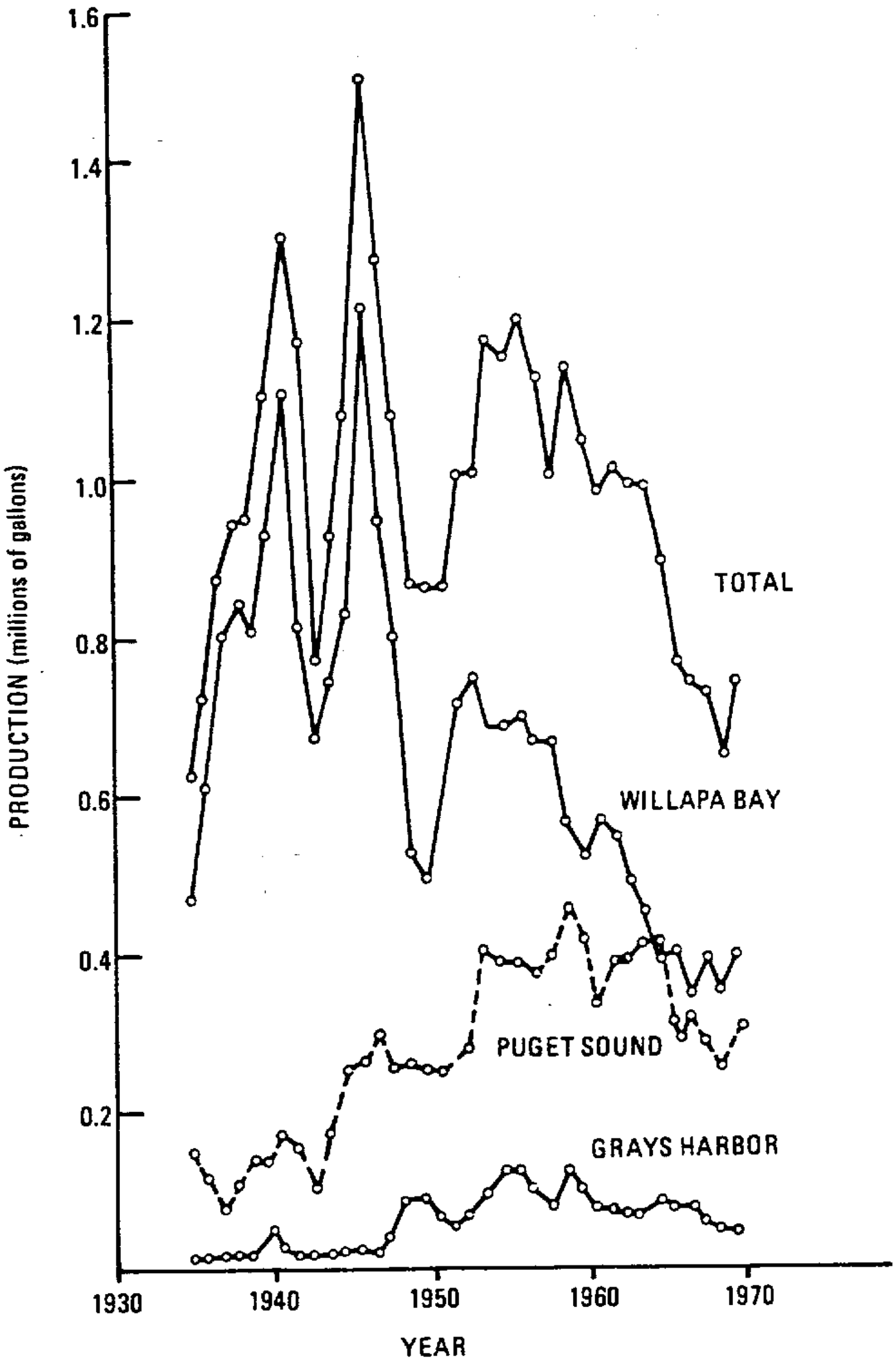

Figure 22. Production (millions of gallons) of Pacific oysters in Washington State, Willapa Bay, Puget Sound, and Grays Harbor, 1935 to 1970 (Shotwell, 1977 as reproduced in Hedgpeth and Obrebsky, 1981).

Figure 23. Production (thousands of pounds) of Pacific oysters in Willapa Bay, 1969 to 1984 (Ward and Hoines, 1985).

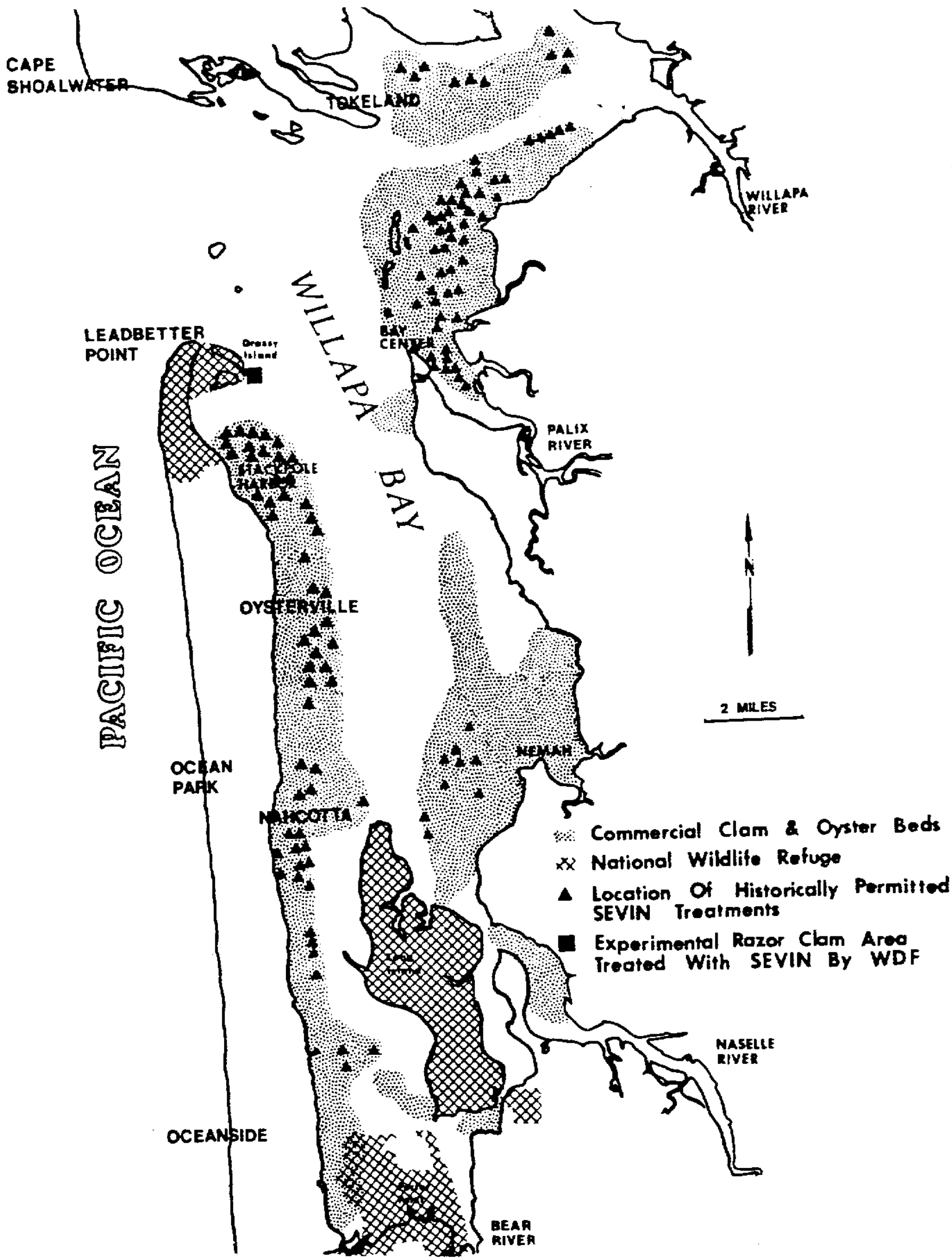

Figure 24. Locations of Sevin treatment in Willapa Bay (Washington State Department of Fisheries and Washington State Department of Ecology, 1985).

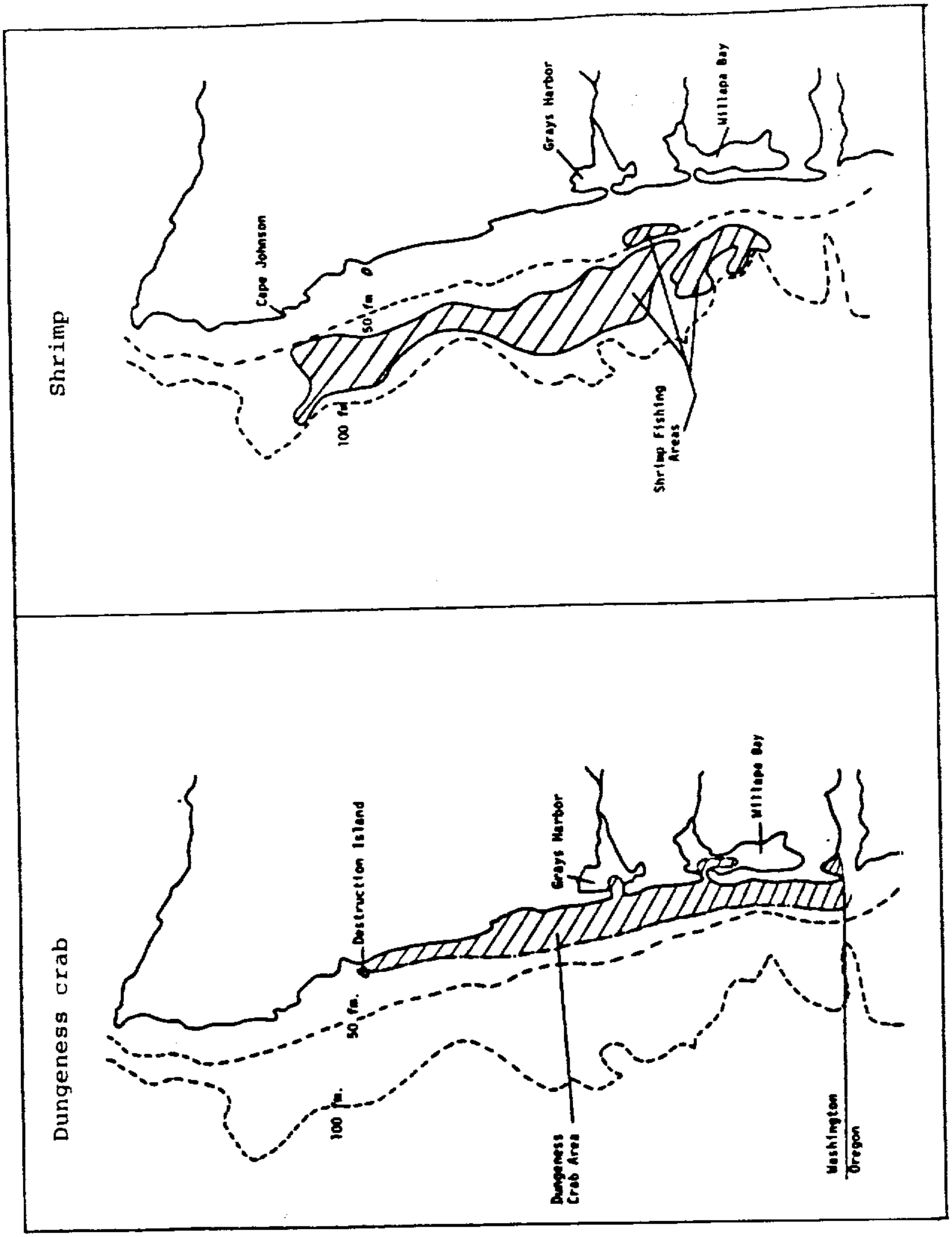

Figure 25. Commercial crab and shrimp fishing areas of coastal Washington (Ferjancic et al., 1981).

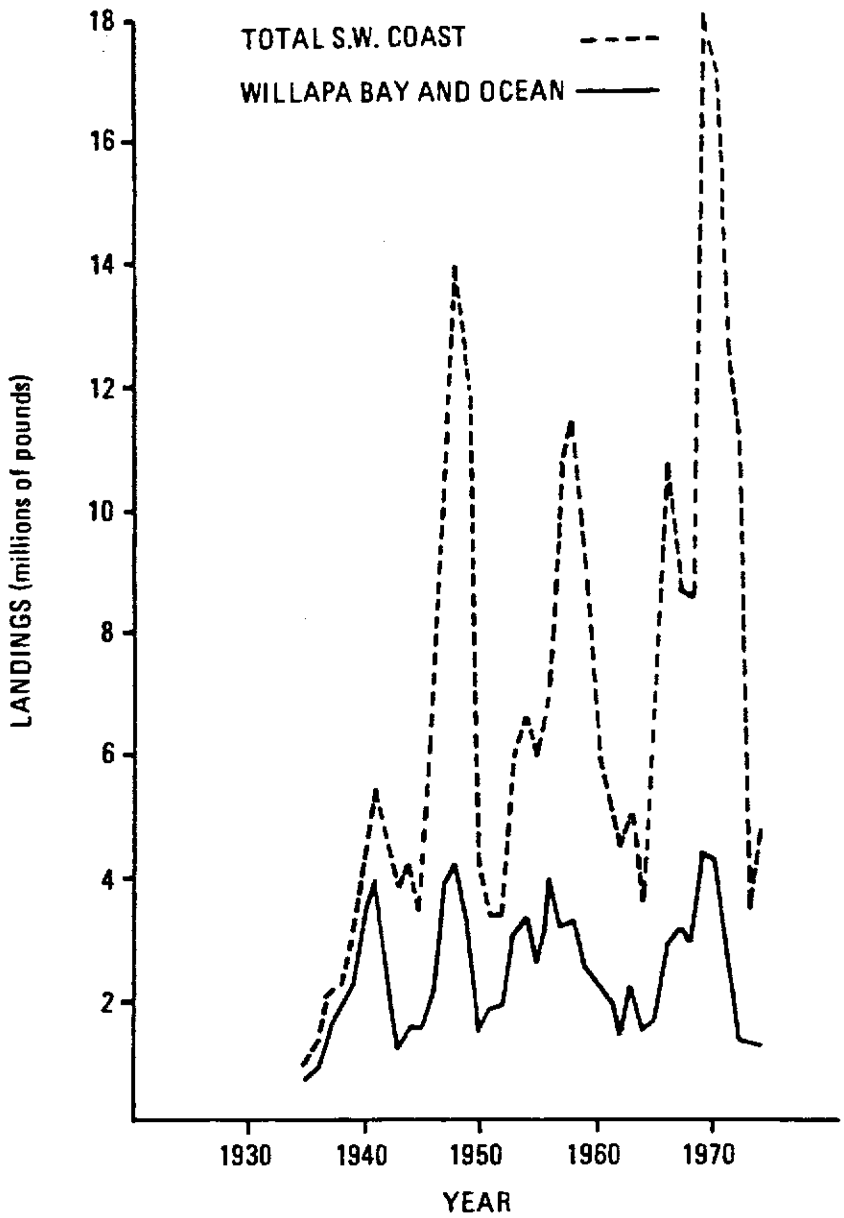

Figure 26. Commercial crab landings (millions of pounds) coastwide and from the Willapa Bay area, 1935 to 1974 (Shotwell, 1977 as reproduced in Hedgpeth and Obrebsky, 1981).

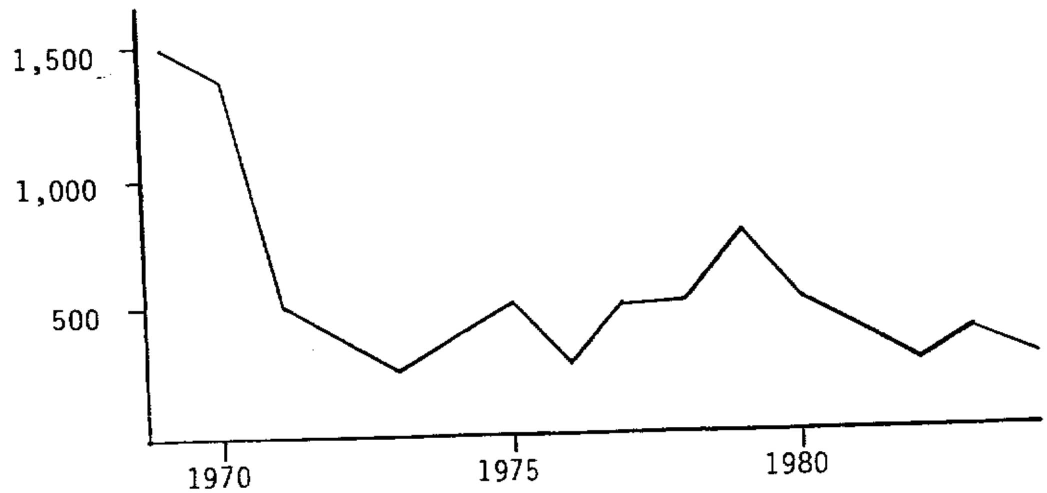

Figure 27. Commercial crab landings (thousands of pounds) from inside Willapa Bay, 1969 to 1984 (Ward and Hoines, 1985).

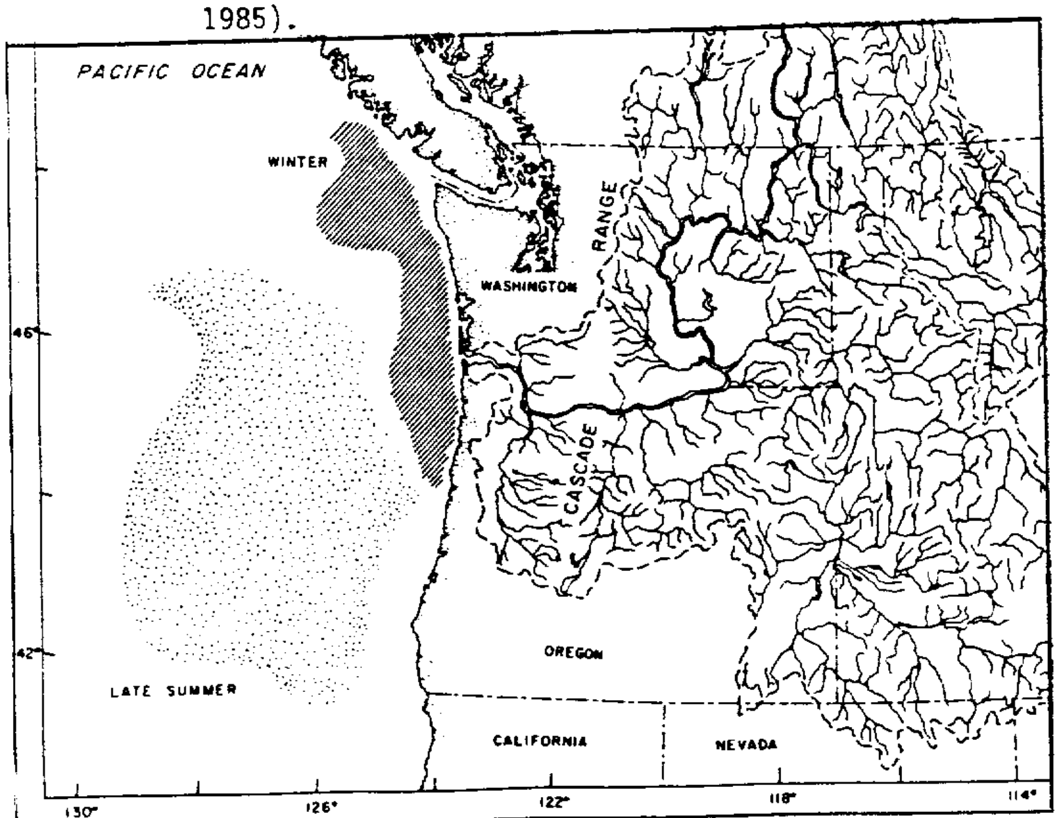

Figure 28. Average seasonal extent of the Columbia river plume offshore (McGary, 1971 as reproduced in Proctor et al., 1980).

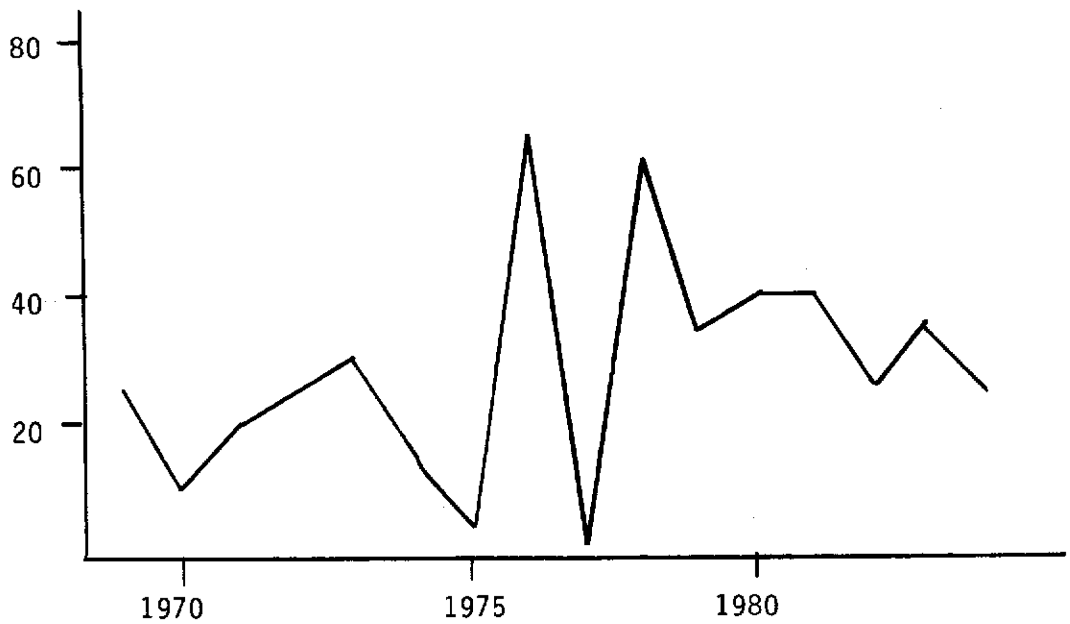

Figure 29. Commercial hardshell clam landings (thousands of pounds) inside Willapa Bay, 1969 to 1984 (Ward and Hoines 1985).

GLOSSARY

Broodyear--year in which a group of fish spawned, either naturally or in the hatchery.

Directed harvest--a fishery conducted to catch one particular species. Same as targeted fishery.

Dorsal stubbing--the deformation of the dorsal fin which identifies a steelhead as having originated in a hatchery.

Escapement--The number of fish escaping the fishery and reaching the spawning grounds.

Escapement goal--that escapement thought necessary to achieve a particular level of harvest desired by management.

Hatchery escapement--escapement of hatchery-origin fish to the hatchery plus strays to the wild. For example, an escapement of 9,000 chinook is needed to allow the required 6,500 to enter the hatchery rack

Marine interception--In this report, the catch of a particular fish stock before it enters Willapa Bay. This is determined by recoveries of tagged fish in the marine fisheries of Alaska, British Columbia, and coastal Washington.

Model--a mathematical equation which, in this case, is used to estimate the terminal run size given data on marine interception and historical return/spawner information.

Overescapement--escapement in excess of the goal.

Return/spawner--The number of fish in the terminal run divided by the number of spawning adults in a certain broodyear.

Terminal area--an area close enough to the parent streams where a fishery can be managed for harvest of single stocksof fish.

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