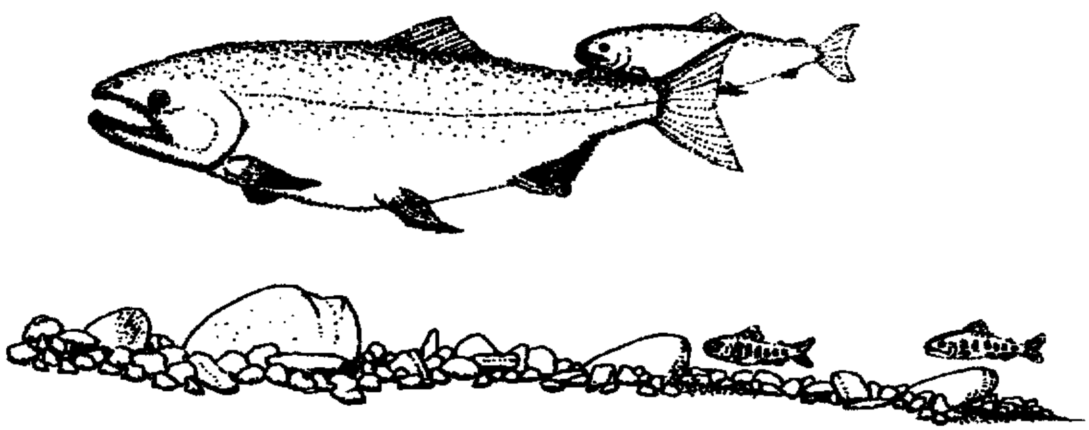
U.S. FISH AND WILDLIFE SERVICE

CHANGES IN POPULATIONS AND DISTRIBUTIONS OF ANADROMOUS FISH, DEMERSAL FISH, AND SHELLFISH UTILIZING NEARSHORE HABITAT IN COMMENCEMENT BAY, 1850 TO 1988



FISHERY RESOURCE OFFICE

OLYMPIA, WASHINGTON

JUNE 1991

Changes In Populations And Distributions Of Anadromous Fish, Demersal Fish, and Shellfish Utilizing Nearshore Habitat In Commencement Bay, 1850 To 1988

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June, 1991

ABSTRACT

Commencement Bay, located on the eastern shore of central Puget Sound, sits adjacent to the city of Tacoma, Washington, and in the inner bay, the Port of Tacoma. Commencement Bay was the scene of drastic environmental alteration since the late 1800s as industry transformed a pristine estuary consisting of mudflats, vegetated shallows, and salt marsh wetlands, into a system of seven industrial waterways penetrating an expanse of dredge-filled flats. Continuing need for biological information to help the U.S. Army Corps of Engineers evaluate permit applications led to an agreement from the U.S. Fish and Wildlife Service to perform this study. The principal study objective was to perform a cumulative, biological impact assessment of special nearshore, intertidal aquatic sites that are or once were found in the bay. Those aquatic sites were identified as intertidal mudflats, vegetated shallows, and salt marsh.

We reviewed available information on species of anadromous salmonids, demersal fish, and shellfish (clams, crabs, and shrimps), and the fate of the habitat they used, the special aquatic sites. Our review covered the period from about 1850 to 1988. To the extent that information made possible, we constucted species assemblages known or assumed present in the habitats within a series of periods up to 1988. Using calculations of special aquatic habitat areas taken from recreated maps (D. Evans and Associates 1991), we related habitat losses over time to relative presence of the various species.

We determined that incremental habitat losses over time, together with widespread contamination of the habitats from toxic organic and inorganic chemicals, had altered species assemblages and severely reduced the production potential of the habitats. We found that all of the special aquatic habitats are of much value as unique components of the estuarine whole, but that their area in acres in Commencement Bay had been reduced to about 4% from that present in 1850.

We recommended candidate areas of greater value for purposes of future protection or restoration in Commencement Bay.

ACKNOWLEDGEMENTS

A number of people were very helpful during the information gathering process. Steve Dilley, U.S. Fish and Wildlife Service (FWS), began the process. Rich Carlson and Jeff Krausmann, FWS, performed library searches, as did Sam Taylor of the Washington Conservation Corps. Alexandra Snyder, Fish Collection Manager at the University of Washington, Seattle, reviewed old fish collection records. Erling Bergerson, Tacoma fishing expert, provided unique information on how it once was in the bay. Brian Baldassin, Marine Biologist at the Point Defiance Aquarium, described past collections and shared broad knowledge of marine communities. Judy Wright, Puyallup Tribal Archivist, reviewed records of tribal history. Joe Anderson and Russ Ladley, Puyallup Tribal Fisheries Department, reviewed data from fish collections. Lee Hoines, Washington Department of Fisheries (WDF), shared fish catch data for central Puget Sound. Bob Gerke, Mary Lou Mills, and Tom Hooper, WDF, provided suggestions. Randy Cooper, Washington Department of Wildlife, provided information. Art Johnson, Washington Department of Ecology, provided information and suggestions. Charles Simenstad, Bruce Miller, and Allen Ducksbury, Department of Fisheries, University of Washington, provided information and suggestions. Bob Harmon, Shoreline College, shared data and impressions from extensive sampling in Puget Sound. Dick Gilmer, Port of Tacoma, provided suggestions. Allen Scholz and Lynn Goodwin, WDF Shellfish Lab, provided information. Cyreis Schmitt and Wayne Palsson, WDF Sand Point Lab, provided information and suggestions. Bill Cleland, Washington Department of Health, provided information. Bruce McCain, National Marine Fisheries Service, provided information and suggestions. To any others whom we have overlooked, we also express our appreciation.

Nancy Duran, FWS, assisted with keyboarding. Eric Knudsen and Joanne Stellini, FWS, reviewed the draft report.

CONTENTS

INTRODUCTION

The U. S. Army Corps of Engineers (USACE) has identified three types of special aquatic habitat sites existing in Commencement Bay estuary, i.e., mud flats, vegetated shallows (eelgrass beds), and wetlands (salt marsh). Prior to the onset of habitat alterations from man's activities at Commencement Bay, these aquatic habitat sites were relatively pristene (Figure 1). These sites have gradually diminished in area as a result of continuing industrialization. In response to Section 404 (b) (1) Guidelines, the USACE determined that a cumulative impact assessment of the nearshore, special aquatic habitat sites should be performed. This assessment would attempt to quantitatively and qualitatively identify the special sites through history and describe their respective use and relative importance to anadromous salmonids, demersal fish, and shellfish. Moreover, the assessment would include the functional value of the special sites to those species that still use them.

A cumulative impact is defined in the Council on Environmental Quality (CEQ) regulations (1978) as follows:

> 'Cumulative impact' is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time. Effects include: (a) direct effects, which are caused by the action and occur at the same time and place; and (b) indirect effects, which are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth-inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.

For the purposes of this assessment, the nearshore/tideflat areas of concern within Commencement Bay were identified as between Point Defiance and Brown's Point (DEA 1990)(Figure 2). Special attention would be placed on the area of Tacoma Harbor.

A separately contracted effort within the scope of the Corps' cumulative impact assessment would be to develop a series of maps depicting the Commencement Bay areas of concern and how the areas of special habitat were altered or diminished by man's activities. Those maps, by David Evans and Associates, Inc. (DEA), are included in this report as Figures 2 to 8.

The U. S. Fish and Wildlife Service (USFWS) agreed to perform the biological portion of the study. Our study objectives were: (1) describe what aquatic animal species existed in the nearshore/tideflats areas of Commencement Bay prior to the onset of industrial development; (2) describe discernable trends of change in presence of those species concurrent with trends of change in the nearshore habitat they utilized; (3) describe the known or assumed present use of nearshore habitat by the remaining species; and (4) identify which specific areas of special aquatic habitat merit future protection from the cumulative effects of man's activities. The aquatic animal species to be described include anadromous salmonids, demersal fish, and shellfish (clams, crabs, and shrimps).

METHODS

Our study objectives required an extensive review of existing information on Commencement Bay. Our review included: (1) searching for documents/reports in a number of libraries, including the Washington State Library (Olympia, WA), the Tacoma Library (Tacoma, WA), the Historical Society Library (Tacoma, WA), the University of Washington Libraries (Seattle, WA), and USFWS libraries (Olympia, WA); (2) telephone/personal interviews with aquatic resource staff of state, federal, and tribal agencies, and staff at the University of Washington (Seattle WA), Shoreline College (Seattle, WA), University of Puget Sound (Tacoma, WA), Point Defiance Aquarium, and the Port of Tacoma (Tacoma, Wa); and (3) we interviewed an area resident having lengthy experience in the bay.

This study was undertaken based on the assumption that the objectives could be achieved through review and analysis of existing information. Given this restriction, i.e., no new research or collection of new data, we accepted the possibility that parts of certain objectives might not be achievable. The period of interest, from about 1850 to the present, includes a considerable portion during which there was very minimal accurate documentation of aquatic species presence. Because of this limitation, we concluded that certain generalized or anecdotal information, if it existed, would have to be given some importance and could contribute to decisions about cumulative impacts. Moreover, assumptions regarding the complete assemblage of aquatic animal species present at particular points in time might be based, at least in part, on generalized assessments in the literature or professional judgement, especially for the earlier period of interest.

We concluded that anadromous salmonids would be the species group most amenable to achieving objective (2), above. However, the general lack of information on standing populations required that we devise another method to describe the trends of change in fish presence and habitat. No known information permitted estimation of the actual, quantifiable impact to the fish runs. However, if we looked at the proportional remaining habitat at a point in time, in terms of its fry/smolt "production potential", then we could at least follow the relative rate of cumulative impact on the runs. This calculation was simplified by combining area values for intertidal mudflat and intertidal emergent marsh (Figures 2 to 8), both for pre 1877, i.e., pre-development, and for the end of the period in question, e.g., the year 1907. Dividing the 1907 value, 4928 acres, by that for 1877, 5979 acres, would give the remaining proportion of available, functional intertidal habitat. Thus, we calculated that a production potential of about 82% remained in 1907, representing a cumulative intertidal habitat loss for anadromous salmonids of about 18%.

HABITAT REQUIREMENTS AND HISTORIC SPECIES OCCURRENCE

Anadromous Salmonids

All of the anadromous salmonid species present in the Puyallup River system, which drains into Commencement Bay, rely to some extent on the nearshore/tideflat habitats. Salmon use estuaries for foraging, undergoing physiological transition from fresh to salt water, migration guidance, and for refuge from predators. The reliance upon estuarine habitat by outmigrating juvenile salmon and their typical patterns of behavior were described by Simenstad et al.(1982):

> "Upon entry to the estuary, juvenile chum and pink salmon usually occupy shallow sublittoral habitats before moving into neritic habitats. Chum remain primarily in these shallow areas until they are 50-60 mm FL, when the fish become more common in neritic habitats. Eelgrass (Zostera spp.) habitats, especially within contained embayments, may be particularly preferred. Juvenile chum usually school in shallow habitats during daylight but disperse into smaller groups at night (Salo et al. 1980)."
>
> "Juvenile coho move directly into neritic waters upon entering the estuary and school much less than pinks and chums. Exposed, cobble, or gravel beaches appear to be preferred nearshore habitats within Puget Sound's fjords (Miller et al. 1978, 1980)."
>
> "Juvenile chinook salmon of different sizes utilize a number of estuarine habitats, however, during their lengthy estuarine residence. Subyearlings and fry occur mainly in salt marshes where these habitats are available. However, mudflat, foreshore areas can be utilized for some time by larger subyearlings before they move into neritic habitats (Stober et al. 1973; Simenstad and Eggers 1981; Congelton et al. 1982). Yearling chinook move directly into neritic habitats without much utilization of salt marsh or other shallow habitats, although neritic areas associated with contained embayments may be preferred."

Like coho salmon, steelhead trout juveniles apparently have little direct need for mudflat and salt marsh habitats, but must be linked to the food web indirectly. Cutthroat trout, however, do apparently rely on these habitats for all of their salt water residency (Trotter 1989).

Individual residence time of juvenile salmon in littoral habitat most correctly takes into account total time in all littoral portions of the estuary, not just individual channels (Simenstad 1983). Maximum individual residence times for the different species were reported by Levy and Northcote (1982): chinook fry, 30 days; chum, 11 days; and pink, 2 days. However, a review of work in Washington State estuaries by others (Simenstad et al. 1982) showed these values to range as follows: chinook, 6 to 189 days; chum, 4 to 32 days; and coho 6 to 40 days. The eventual period of residence in the estuary mainstem channel also varies considerably by species (Simenstad 1983). Juvenile pink salmon appear to emigrate directly out of the estuary, while chum may stay in the main channel up to 4 weeks. Fish size at entry also determines length of residency. Smolts may stay only for a brief transition period. Chinook and coho use estuarine channels principally as corridors for direct emigration to salt water. Comparatively little is known regarding the use of estuarine habitats by steelhead trout (R. Cooper, Wash. Dept. Wildlife, pers. comm.).

The pattern of prey resource utilization among juveniles of the salmon species appears to have evolved much to their mutual benefit by minimizing competition (Simenstad 1983). Pink fry rapidly move to pelagic channel or neritic habitats, feeding mainly on calanoid copepods and larvaceans. Chum fry, however, remain in shallow sublittoral habitats, especially sand-eelgrass, for weeks while feeding on epibenthic zooplankton, particularly harpacticoid copepods and larvaceans. Later, at a larger size, chum move to pelagic channel or neritic habitats where they feed on calanoid copepods, decapod larvae, and larvaceans. Juvenile coho feed primarily on gammarid amphipods while in shallow habitats, but soon move to pelagic or neritic habitats where they feed on decapod larvae and euphausiids. Chinook fry move mainly into shallow sublittoral, salt marsh, or mudflat habitats where they feed on gammarid amphipods, cumaceans, and emergent and drift insects. When approximately 60 mm FL, they too move into pelagic or neritic habitats where they feed on drift insects, and decapod and fish larvae (Simenstad 1983).

It is important to recognize that the major prey of young salmonids in estuarine habitats tend to be detritus feeders, thus the food web is detritus based (Healey 1982). Any impact on the habitats that contribute to detritus production must have some impact on the higher levels of the food web.

The feeding strategy shared among the anadromous salmonids is to utilize a diverse array of prey resources, often in extremely high density, which allows them to sustain high growth rates while occupying a relative refugia from predation (Simenstad et al. 1982). This strategy appears to narrow their period of vulnerability to predation that would exist outside of the estuary, allowing them to grow to a safer size while in the estuary.

Residence time of migrating adult salmon that enter estuarine channels ranges from 1 to 6 weeks (Simenstad et al. 1982). During this period, salmon are particularly vulnerable to harvest.

<u>Demersal Fish</u>

Simenstad (1983) showed that, among demersal species that commonly occur in Pacific Northwest regional estuaries, nine species are prevalent in estuarine channels (Table 1). A thorough review of fish collections made in Puget Sound was reported by Miller and Borton (1980). They compiled a total of 16 fish species that were observed in waters of Commencement Bay (Table 2). Of those 16 species, 7 are considered demersal, and among those that are non-demersal, nearly all are anadromous salmonids. One species, the ragfish, is not found nearshore. Among those species Simenstad listed as prevalent (Table 1), the peamouth, Pacific sand lance and Pacific staghorn sculpin had not been recorded in Commencement Bay (Table 2). These lists do not necessarily include all possible demersal species that once occurred in the nearshore/tideflat waters of Commencement Bay. Fish species recorded from the Nisqually Delta and estuary and Quartermaster Harbor are listed for comparison to those recorded in Commencement Bay (Table 2).

A number of other species are listed by DeLacey et al. (1972) as recorded in the sampling area "Central Puget Sound", from Point Defiance to Possession Point. We regard these as likely to have occurred in Commencement Bay, but only six appear to be both demersal and to use nearshore habitat: <u>Apodichthys flavius</u>, the penpoint gunnel; <u>Lepidogobius lepidus</u>, the bay goby; <u>Hexagrammos</u>

decagrammus, the kelp greenling; Myoxocephalus polyacanthocephalus, the great sculpin; Psychrolutes paradoxus, the tadpole sculpin; and Scorpaenichthys maramoratus, the cabezon.

The variation in demersal fish assemblages in Puget Sound estuaries relate principally to the relative extent of salinity intrusion, the characteristics of the freshwater watershed, the geographic region and the estuarine environment (Simenstad 1983). Usually, the greatest number of species and abundances of demersal fishes occurs within the head (upper) region or low salinity regions of the estuary. Fish movements, recruitment of juveniles and effect of river discharge on salinity distribution affect seasonal shifts in demersal fish assemblages.

The feeding behavior of demersal fish generally is to feed on fauna/flora that are found at the epibenthic level, i.e., associated with the surface of the bottom but also with the water column directly above the bottom. The majority of those demersal species observed in Commencement Bay are facultative feeders, i.e., they may feed on diverse prey from several trophic levels. Blaylock and Houghton (1981) observed that the more common species of flatfishes showed a strong preference for benthic invertebrates as prey items.

Shellfish

Clams

Mud and muddy sand support large populations of animals (Kozloff 1973). Discounting microscopic animals, others present fall into three principal groups: polychaete annelids, bivalve molluscs, and crustaceans. Intertidal mudflat provides suitable habitat for clams. Muddy sand is likely to support abundant Macoma nasuta, the bent-nosed clam, and other species of Macoma as well (Wisseman et al. 1978, Kozloff 1973). Other Macoma spp. recorded at the site of the former mudflats, near the Puyallup River, include M. balthica, M. calcarea, and M. incongrua (Dames and Moore 1982). Also present are Tresus capax, the horse clam, and less common, Panope generosa, the geoduck (Kozloff 1973). Clinocardium nuttallii, the heart cockle, may be present. In locations of reduced salinity, closer to a freshwater channel, and a mix of mud with sand or gravel, Mya arenaria, the soft-shell clam, may occur. Also likely on the mudflat in association with any rock present, was Ostrea lurida, the Olympia oyster.

It is likely that other clam species were present, based on collections from similar estuarine mudflats immediately adjacent to the mouth of the Nisqually River, located in south Puget Sound (Wisseman et al. 1978). These include Cryptomya californica, the false mya, Mysella tumida, Transenella tantilla, the little transenella, Solen sicarius, the jackknife clam, and Lucinoma annulata.

Intertidal emergent marsh, or salt marsh, likely provided habitat for some clam species, and most likely in association with the sloughs draining the marsh habitat. Wisseman et al. (1978) found Macoma balthica and M. inquinata in such hatitat at the Nisqually estuary.

Inner bay, intertidal beaches, along much of the north shore, and along much of the south shore of Commencement Bay consisted primarily of gravel substrate. In such protected situations, these beaches most likely supported Saxidomus giganteus, the butter clam, and abundant littleneck clams (Kozloff

1973). Also present, but less abundant, should have been Venerupis tenerrima, the thin-shelled clam.

Bordering the band of intertidal habitats around Commencement Bay and expanding into deeper water there most likely were areas of Zostera marina, eelgrass (E. Bergerson, pers. com.; B. Balisson, pers. com.; Meyer and Vogel 1978; DEA 1991). Clams commonly found in eelgrass habitat are the geoduck, the bent-nose clam, Macoma secta, the white sand clam, the soft-shell clam, the little transenella clam, the heart cockle, and Pecten sp., a scallop (Thayer and Phillips 1977, Kozloff 1973).

Crabs

Crabs utilize habitat in both the mudflats and the salt marsh (Kozloff 1973). On the mudflats, Cancer magister, the Dungeness crab, and Cancer productus, the red crab, may occur in the intertidal area. In the eelgrass, Pugettia gracilis, a spider crab, Pugettia producta, the kelp crab, and Telmessus cheiragonus, the helmet crab, are likely to be found. At the Nisqually delta mudflat, Pinnixa schmitti, a pea crab, was commonly found (Wisseman et al. 1978). The largest crab, the Dungeness, has been found to migrate extensively between greater subtidal depths and the intertidal area, depending on several factors, particularly age (Simenstad 1983).

In the salt marsh, Hemigrapsus nudus, the purple beach crab, retreats into a burrow and may be common (Kozloff 1973). Hemigrapsus oregonensis, the hairy shore crab, was found abundant in the Nisqually River salt marsh (Wisseman 1978) and it could have occurred at Commencement Bay as well.

Shrimps

In the intertidal mudflats, two burrowing shrimp, Callianassa californiensis, a ghost shrimp, and Upogebia pugettensis, the blue mud shrimp, occur in muddy sand with enough clay content to support tunnels (Kozloff 1973). The two may be found inhabiting the same habitat.

Eelgrass beds provide one of the habitats used by Heptacarpus sp., the broken-back shrimp, Pandalus danae, the coon-stripe shrimp, and Crangon sp., the snapping shrimp (Thayer and Phillips 1977).

RESULTS

The Years 1850 to 1877

The first recorded development was the construction in 1874 of a segment of railroad (Figure 2) passing through the southwestern portion of the estuary (DEA 1991). The habitat type affected was largely intertidal emergent marsh, i.e., salt marsh. An estimated 10 acres of combined salt marsh and mudflat were filled.

Anadromous Salmonids

Anadromous salmonids present in the bay area during the years 1850 to about 1874 were unaffected by development. Prior to this, only minimal impact from seasonal fish harvest by resident Indians and the relatively few non-Indians affected anadromous salmonids. Review of accounts of that period indicate that large runs of anadromous salmonids annually entered the bay and soon ascended the Puyallup River to spawn. Lesser runs also ascended Wapato and Hylebos creeks. Excerpts and sources supporting these conclusions are listed in Table 3. More specific information is not known and accurate records for run escapement or catch were not recorded until many years later.

Demersal Fish

We assume that all of the demersal nearshore species shown in Tables 1 and 2, as well as the six species added from DeLacey et al. (1972) above, were still present and unaffected by the limited development in Commencement Bay in 1874. The virtual pristine condition of the bay must have provided all requirements for full utilization of the demersal habitats.

Clams

We assume that the bivalve assemblages described above in HABITAT REQUIREMENTS are accurate and should be used for comparative purposes. We also assume that the beaches, mudflats, and marsh habitats within the nearshore/tideflat areas of Commencement Bay (Figure 1) all contained clams and oysters in varying levels of abundance, according to their habitat requirements. This assumption is based on a number of anecdotal sources (Table 4). No information is known that specifically describes species and their populations present in the bay up to 1874. The railroad development across the southwest portion of the salt marsh likely resulted in an unknown but minimal loss to the populations of Macoma balthica and Macoma inquinata and their preferred habitat. A small area of mudflat habitat, and the clams and oysters there, were also destroyed.

Crabs

We assume that the assemblages of crab species described above in HABITAT REQUIREMENTS are accurate and should be used for comparitive purposes. We assume that the beaches, mudflats, and marsh habitats within the nearshore/tideflats areas of the bay (Figure 1) all contained optimal numbers of crabs, according to their habitat requirements. No known information describes those species and their populations present up to 1874. The railroad development across the southwestern portion of the salt marsh likely did result in an unknown but minimal loss to at least the population of Hemigrapsus nudus and its preferred salt marsh habitat.

Shrimps

The relatively pristine conditions that existed in Commencement Bay up to 1874 provided considerable suitable habitat for the shrimps described above in HABITAT REQUIREMENTS. The impacts caused by the railroad construction across the southwestern salt marsh should not have had more than very minimal effect on any shrimp populations or their habitat.

The Years 1877 to 1894

During this period, an addition to the railroad was extended generally northward across a channel of the Puyallup River, across Boot Island, and then across the full length of the mudflats to end at a loading wharf (Figure 3). At least 31 acres of combined mudflat and salt marsh were either filled or destroyed (DEA 1991). Part of the destruction was due to construction of wharves and piers along the southwestern edge of the estuary.

Anadromous Salmonids

The development that occurred during this period began to have some impact, although minimal, on anadromous salmonid species. The impact affected salmonid fry and juveniles, which are secondary level consumers, feeding on organisms that are primary level consumers. Elimination of an area of salt marsh not only reduces a source of refuge, but results in the proportional destruction of detritus-producing plant species, organic detritus being a basic component of the food web. Elimination of mudflat similarly results in a proportional destruction of habitat essential to the production of prey organisms. Chum fry and chinook fry, in particular, rely on these habitats for food. Thus, a minimal decline in the annual production of young salmon from the bay may have led to a corresponding, but reduced decline in the adult runs.

Demersal Fish

The rail extension across the mudflat eliminated a comparatively small amount of habitat used by demersal fish species. Among the species most likely affected were English sole, sand sole, starry flounder, Pacific staghorn sculpin, snake prickleback, Pacific sand lance, pile perch, and shiner perch (Simenstad 1983; Pearce et al. 1982; Weitcamp and Schadt 1981; Fresh et al. 1979).

Clams

The rail extension across the salt marsh eliminated a small amount of habitat that likely was used by Macoma balthica and Macoma inquinata. The mudflat area eliminated by the construction could have supported a number of additional species of clams that prefer substrate containing some mix of mud (see HABITAT REQUIREMENTS above).

Crabs

The railroad extension across the salt marsh likely resulted in a minimal reduction in the population of Hemigrapsus nudus and its preferred habitat. The contruction across the mudflat likely had a minimal impact on the populations of Dungeness crab, red crab, and the pea crab.

Shrimps

The railroad extension across the mudflat likely resulted in a minimal reduction in the populations of the two burrowing shrimp, Callianassa californiensis, and Upogebia pugettensis.

The Years 1894 to 1907

Development during this period resulted in the loss of 605 acres of intertidal mudflat and 415 acres of salt marsh, for an estimated net loss of 1020 acres of intertidal habitats (Figure 4, Table 5). An estimated 870 acres of the estuary were filled during this period. Habitat losses during this period dealt a serious blow to the general health of the Commencement Bay estuary. Not only was the acreage lost to natural production, but riverine sediment distribution patterns were significantly altered by redirecting the river's flow within the delta (DEA 1991). Moreover, those alterations significantly affected the patterns of fresh and saltwater mixing which in turn must have modified the suitability of areas as habitat for many species (Simenstad 1983).

Anadromous Salmonids

We assume that the combined development and loss of habitat areas that occurred during this period had an impact on anadromous salmonid runs in the Puyallup River. All of the species relied to some extent on food production and temporary refuge that the lost habitats provided. Some level of additional decline in the annual production of young salmon may have led to a corresponding, but reduced decline in the adult runs. This, in addition to any decline that occurred due to previous development (Figure 3), constitutes an initial cumulative impact on anadromous salmonids.

It is likely that additional impact on runs resulted from complete or partial migration/emigration blocks or delays as a result of redirection of the river channel on the delta. The construction of new waterways and a blind basin may have caused similar delays and increased rates of predation on fry. Returned adults may have been exposed to increased capture (poaching) and predation.

As described in METHODS, we used the values in Table 5 to calculate an intertidal habitat production potential for anadromous salmonids, in 1907, of 82%. This production potential is particularly applicable to chinook and chum salmon because they need both mudflat and salt marsh habitat. At the other extreme, pink salmon spend little time in these habitats, but still must be linked to the food web indirectly. Coho salmon and steelhead trout apparently have little direct need for mudflat and salt marsh habitats, but also must be linked to the food web indirectly. Cutthroat trout rely on these habitats for all of their salt water residency.

Demersal Fish

We assume that the development and loss of habitat, including that of 29% of intertidal mudflat, during this period also had a detectable impact on intertidal demersal species. All of those species relied to some extent on food production that the lost habitats provided. Among the species most likely affected were English sole, sand sole, starry flounder, Pacific staghorn sculpin, snake prickleback, Pacific sand lance, pile perch, and shiner perch (Simenstad 1983; Pearce et al. 1982; Weitcamp and Schadt 1981; Fresh et al. 1979). The resulting fish production loss during this period, plus that from the previous period's development (Figure 3), constitutes the initial cumulative impact on demersal species.

Clams

The elimination of an additional 415 acres of salt marsh, or over 10% of that available before the year 1877, was a significant loss for clams. The elimination of an additional 605 acres of mudflat during this period, or 29% of the pre-development acreage, represented a substantial loss of clams and oysters and their habitat. These losses, plus those preceding, constitute the initial cumulative impact on clam and oyster species.

Crabs

The elimination of an additional 415 acres of salt marsh and 605 acres of mudflat was a considerable reduction in habitats for crab species. An estimated 870 acres were filled that had provided habitat for one or more crab species. Populations of Dungeness, red, spider and other crabs were diminished, presumably in proportion to the percentage of habitat area lost.

Shrimps

The elimination of 605 acres of mudflat during this period may have resulted in proportional reductions in the populations of the two burrowing shrimp, Callianassa californiensis, and Upogebia pugettensis. Filling along the southern shore of the bay, adjacent to the new City Waterway and at Ruston (Figure 4), may have eliminated some eelgrass beds. Eelgrass beds provide one of the habitats used by Heptacarpus sp., the broken-back shrimp, Pandalus danae, the coon-stripe shrimp, and Crangon sp., the snapping shrimp (Thayer and Phillips 1977). These populations were proportionally reduced.

The Years 1907 to 1917

Development during this period resulted in the loss of 542 acres of intertidal mudflat and 64 acres of salt marsh, for an estimated total net loss of 606 acres of intertidal habitats (Figure 5, Table 5). An estimated 543 acres of the estuary were filled during this period. Taken as a whole, the development during this 10 year period set the stage for the eventual, near total destruction of the Commencement Bay estuary. Two streets were extended to the north, almost the full width of the estuary, and both apparently were eventually diked to keep saltwater out of the still extant salt marsh beyond. The lower reach of the Puyallup River was channelized, thus drastically altering the natural process of distribution and mixing of freshwater, and of sediment distribution across the delta. Three additional waterways were added northward, effectively breaking up the continuum of access to intertidal mudflat and salt marsh that had existed across the bay front. Altogether, these alterations very significantly affected the former patterns of animal migrations and fresh and saltwater mixing over the mudflat and salt marsh. Very clearly, this in turn must have modified the suitability of large areas as habitat for many species.

Anadromous Salmonids

The loss of habitat during this period probably caused significant impact on anadromous salmonid runs in the Puyallup River. All of the species relied, either directly or indirectly, on the lost habitats. This additional decline in the annual production of young salmon from the estuary probably led to a corresponding, but reduced decline in the adult runs. This, in addition to any declines caused by previous development (Figure 4), resulted in further cumulative impacts on anadromous salmonids. We calculate a production potential of 72% for 1917, i.e., about 72% of the combined mudflat and salt marsh habitats remained intact, representing an estimated loss of 28% of habitats needed for salmon production.

Predation on emigrating fry/smolts likely increased from the completed channelization of the Puyallup River. Emigrating fish could no longer disperse into the full interface of the river against the estuarine habitats, but instead were forced to funnel their movement through the narrow gap at the end of channelization (Figure 5). The seasonal emigrations of large numbers of small salmonids through the narrowed mouth likely attracted a wide range of predators on these fish, resulting in a new form of decline in the runs.

Demersal Fish

The loss of intertidal habitat due to development during this period also resulted in further, cumulative impacts on intertidal demersal species. All of those species relied to some extent on food production that the lost habitats provided. The loss of habitat, particularly of mudflat, further reduced the physical space or "carrying capacity" that was previously available to the species English sole, sand sole, starry flounder, Pacific staghorn sculpin, snake prickleback, Pacific sand lance, pile perch, and shiner perch.

Clams

Loss of an additional 64 acres of salt marsh resulted in further reduction of clams. Elimination of an additional 542 acres of mudflat during this period reduced that habitat area to about 44% of the pre-development mudflat acreage.

Crabs

Elimination of an additional 64 acres of salt marsh and 542 acres of mudflat caused the further reduction in habitats for crab species. An estimated 543 acres were filled that had provided habitat for one or more crab species. Populations of Dungeness, red, spider and other crabs were diminished, presumably in proportion to the percentage of habitat area lost.

Shrimps

Elimination of 542 acres of mudflat during this period may have resulted in further, proportional reductions in the populations of _Callianassa californiensis_, and _Upogebia pugettensis_. Filling with smelter slag material at Ruston (Figure 5), may have eliminated eelgrass beds within some radius of the site. In retrospect, we know that this material was extremely toxic to all forms of marine life. Beds of eelgrass were present from "Puget Sound Mill [on the south shore of the bay] to Point Defiance Mill, a distance of about two miles" (E. Bergerson, pers. comm.). Eelgrass beds provide one habitat used by _Heptacarpus sp._, the broken-back shrimp, _Pandalus danae_, the coon-stripe shrimp, and _Crangon sp._, the snapping shrimp (Thayer and Phillips 1977). These populations were proportionally reduced.

The Years 1917 to 1927

Development during this period resulted in the loss of 162 acres of intertidal mudflat and 75 acres of salt marsh, for an estimated total net loss of 237 acres of intertidal habitats (Figure 6, Table 5). An estimated 119 acres of the estuary were also filled during this period. Impacts from development during this 10-year period were primarily in the form of expansion of the Hylebos Waterway with associated dredging and filling of an adjacent area, mostly salt marsh, along the southern edge of the waterway. Development on the previously filled areas was intensified with construction of new piers, wharves, yards and various structures.

Anadromous Salmonids

Loss of habitat during this period had further impact on Puyallup River anadromous salmonids. Additional decline in the annual production of young salmon led to a corresponding, but reduced decline in the adult runs, particularly in Hylebos Creek. By 1927, about 68% of the combined mudflat and salt marsh habitats remained intact, representing an estimated loss of 32% of habitats originally available to salmon production.

Demersal Fish

Loss of intertidal habitat areas due to development during this period resulted in further, cumulative impacts on intertidal demersal species. All of those species relied to some extent on food production that the lost habitats provided. The loss of habitat area, particularly of mudflat, further reduced the physical space or "carrying capacity" that was previously available to the species English sole, sand sole, starry flounder, Pacific staghorn sculpin, snake prickleback, Pacific sand lance, pile perch, and shiner perch.

English and Dover soles were still very plentiful in the vicinity of the sewage outfall at Old Tacoma (E. Bergerson, pers. comm.). These species and "perch" were also plentiful along the mudflats of the inner bay.

Clams

The loss of an additional 75 acres of salt marsh resulted in further reduction of the clam species found there. The elimination of an additional 162 acres of mudflat during this period reduced that habitat area to about 37% of the pre-development mudflat acreage.

Along the north shore, from the vicinity of Brown's Point to near the present entrance of Hylebos Waterway, cockles, and butter, steamer, and geoduck clams were very plentiful (E. Bergerson, pers. comm.). Also, apparently during this period, clams "of all species" were plentiful along the south shore of the bay, but they were gone within a few years after the onset of operations of new mills near Old Tacoma.

Crabs

The elimination of an additional 75 acres of salt marsh and 162 acres of mudflat caused the further reduction in habitats for crab species. An estimated 119 acres were filled that had provided habitat for one or more crab species. Populations of Dungeness, red, spider and other crabs may have declined in proportion to the percentage of habitat area lost.

The dumping of slaughtered poultry waste from a wharf located at the end of one of the more southerly waterways attracted a high density of Dungeness crabs (E. Bergerson, pers. comm.). In excess of 100 large Dungeness crabs could be caught in one crabbing effort near this location. Dungeness crabs were plentiful "all along the edge of the mudflats of the bay."

Shrimps

The elimination of 162 acres of mudflat during this period may have resulted in further, proportional reductions in the populations of _Callianassa californiensis_, and _Upogebia pugettensis_.

The Years 1927 to 1941

Development during this period resulted in the loss of 133 acres of intertidal mudflat and 1676 acres of former salt marsh, for an estimated total net loss of 1809 acres of intertidal habitats (Figure 7, Table 5). An estimated 337 acres of the estuary were also filled during this period. Impacts from development during this 15-year period were primarily from dredging and filling for expansions of Hylebos, Wapato, Sitcum, and St. Paul Waterways. Extensive habitat areas were filled beyond the east end of Hylebos Waterway, east of the present location of Sitcum Waterway, and adjacent to the Puyallup Waterway, east of Lincoln Street. Major alterations of the drainage patterns in most of the remaining marsh areas, in association with apparent conversions to agriculture caused widespread degradation of this habitat for estuarine life.

Anadromous Salmonids

Additional loss of intertidal habitat had impacts on Puyallup River anadromous salmonids. Declines in the annual production of young salmon probably led to corresponding, but smaller declines in the adult runs, particularly in Hylebos and Wapato creeks. The revised production potential by 1941, was about 38%, down from 68% in 1927. About 62% of the intertidal habitat important to salmon production had been destroyed.

Demersal Fish

Further loss of intertidal habitat resulted in further, cumulative impacts on intertidal demersal species. All of those species relied to some extent on food production that the lost habitats provided. The habitat loss resulted in the further decline in populations of English sole, sand sole, starry flounder, Pacific staghorn sculpin, snake prickleback, Pacific sand lance, pile perch, and shiner perch.

The effects of uncontrolled dumping of both solid and liquid waste materials in Commencement Bay became detrimental to fish (Washington Department of Ecology (WDE) 1982). A long-time area resident informed WDE that the Hylebos Waterway was clean until the late 1920s, and that fish were plentiful there. But, during the 1930s the water quality deteriorated and fish became scarce. This condition continued into the 1940s. Dumping of wood processing chemical wastes, including sulfides, was blamed.

Clams

Loss of an additional 1676 acres of salt marsh resulted in further reduction of the clams. The elimination of an additional 133 acres of mudflat, that supported various other clam species, reduced that habitat area to about 30% of the pre-development mudflat acreage.

Crabs

Elimination of 1676 acres of salt marsh and 133 acres of mudflat caused further reduction in habitats for crabs. About 330 acres were filled that had provided habitat for one or more crab species. Populations of Dungeness, red, spider and other crabs probably declined in proportion to the habitat lost.

Uncontrolled dumping of both solid and liquid wastes in Commencement Bay became detrimental to crabs (WDE 1982). A long-time area resident informed WDE that the Hylebos Waterway was clean until the late 1920s, and that crabs were plentiful there. But, during the 1930s the water quality deteriorated and crabs became scarce. This condition continued into the 1940s. Dumping of wood processing chemical wastes, including sulfides, was blamed.

Shrimps

The elimination of 133 acres of mudflat during this period may have resulted in further, proportional reductions in the populations of the burrowing shrimp, Callianassa californiensis, and Upogebia pugettensis.

The Years 1941 to 1988

Development during the years 1941 to 1988 resulted in the loss of 445 acres of intertidal mudflat and 1587 acres of former salt marsh, for an estimated total net loss of 2032 acres of intertidal habitats (Figure 8, Table 5). An estimated 3136 acres of the estuary were also filled during this period. In 1988, only 187 acres of intertidal mudflat and 57 acres of intertidal salt marsh remained in Commencement Bay (DEA 1991). During this period, the remaining areas of isolated marsh were filled. The Hylebos and Blair (formerly Wapato) Waterways were greatly expanded to the east. Additional filling occurred at Sitcum and St. Paul Waterways. Extensive dredging occurred at most, if not all, waterways. A proportionally large part of remaining eelgrass beds disappeared, due to undetermined cause, along the north shore from beyond Brown's Point to about 2 miles into the bay (B. Baldassin, Point Defiance Aquarium, pers. comm.).

During this final period, development virtually eliminated the remnants of natural, intertidal, estuarine habitat. The intertidal habitat remaining is essentially an artificial byproduct of industrial development, with the exception of some habitat areas along the outer north and south shores of the bay.

Anadromous Salmonids

We calculate that the salmonid production potential of the estuary in 1988 was 4% of the historic potential. While this statistic is only an indicator of the estuary's potential as a source of food and refuge, it represents a very significant, dramatic alteration of that natural system. We assume that the elimination of such a significant proportion of intertidal, estuarine habitats must have contributed to further declines in the production of fry/smolts from the estuary.
Declines in the runs of the Puyallup River have been described (Salo and Jagielo 1983). Unfortunately, we find no meaningful way to isolate anadromous salmonid declines caused by the destruction of the Commencement Bay estuary from those caused by other impacts. Other assumed causes of declines in the runs, some documented (Salo and Jagielo 1983) and some only assumed, have been: continuous and inadequately screened water diversion; continuous and excessive water withdrawal from the river channel; dam operations; improper logging procedures; eliminated freshwater habitat by continued development in the watershed; overfishing; and possibly various negative effects of hatchery supplementation in the Puyallup watershed (Miller et al. 1990).

In recent years, research has been performed to better determine the distribution and use of the remaining intertidal habitats by anadromous salmonids. The Puyallup Tribe collected beach seine data at a number of sites around the bay from 1980 to 1987 (Figure 9)(Puyallup Tribal Fisheries Division unpubl). They captured chinook juveniles at all 13 locations, with the exception that none were caught at one or two locations in some years. The highest catch per effort occurred at locations nearest the mouth of the Puyallup River. The lowest catch per effort was usually in the Hylebos Waterway. Chum fry were present at all locations, but with less consistency and not in all years. In most years, more chum were caught at the outer north and south shore locations. Coho were usually the least caught at a location, and they were most often caught at the outer shore locations.

Weitcamp and Schadt (1981) reported on beach seining performed at eight nearshore locations in the bay during 1980. Chinook catch per effort was highest at the location nearest the mouth of the Puyallup River, but they were caught at all stations, including the outer shore and upper Hylebos Waterway locations. Their numbers peaked in May. Some pink fry were also caught at all beach seine locations, but they were most abundant at the north shore outer location. Their numbers peaked in April. Relatively few chum fry were caught. Their numbers were highest in the Hylebos Waterway and at the outer north shore location. A much smaller number of cutthroat trout and very few steelhead trout were caught. Trout were captured either near the river mouth or at the outer north shore location.

Beach seining during 1983 reported by Duker et al. (1989) was performed at the same general locations. Their results confirmed observations made elsewhere that chum and chinook initially use the nearshore habitat, later moving offshore and outward. Coho were only briefly captured in nearshore habitat.

Given the present general absence of natural, intertidal rearing areas, the areas under piers, which is considerable, may offer some refuge from predators and currents (Ratte and Salo 1985). Ratte and Salo reviewed work in the bay by others (Simenstad et al. unpublished) reflecting the changes forced on salmon in the developed bay:

> "Prey composition was highly skewed toward planktonic and neustonic organisms in Commencement Bay, whereas in an undeveloped estuary epibenthic organisms dominate the diet of juvenile salmonids (Fresh et al. 1979). This is due to an overall scarcity of preferred wetland foraging habitats in Commencement Bay. However, juvenile salmonids were often able to focus their foraging upon locales where wetland habitats were available and the associated harpactocoid copepods and chironomids (preferred prey items) could be found."
>
> "There was a size-dependent shift from epibenthic to planktonic and neustonic feeding ecology displayed by chum salmon at 45-55 mm FL and by chinook salmon at 65-75 mm FL. The patchy distribution of planktonic and neustonic prey forced the fish to obtain a wide area to secure food."

Adjustments in salmon behavior cannot be expected to overcome the lost benefits of abundant foraging opportunity that existed in the bay before development. Cordell and Simenstad (1988) noted that loss or degradation of nearshore habitats that support key prey items for emigrating salmon fry may decrease early life-history survival. Present intertidal habitats cannot support the numbers of salmon that once were found there. Any salmon and trout fry/smolts in excess of carrying capacity must go elsewhere at the risk of facing more predators and other hazards.

Demersal Fish

The area of intertidal mudflat that remained in 1988, 187 acres, was about 9% of that available to demersal fish in 1877. This cumulative loss, over the years of development, undoubtedly reduced the populations of demersal fish species. Being epibenthic and benthic feeders, they were attracted to and supported by the prey that the mudflat areas provided. The loss of over 90% of that habitat could only mean that far fewer demersal fish exist in Commencement Bay intertidal habitats in 1988.

We are not aware of any data that can be used to make a reliable estimate of the populations of demersal fish species in the nearshore habitats. There have been several reports of fish captured or observed nearshore in Commencement Bay since 1980 (Salo and McComas 1980; Weitcamp and Schadt 1981; Dames and Moore 1982; Jones and Stokes Associates 1989; Thom et al. 1990). Combined, the species captured/observed in these reports provide a reasonable representation of what was present in the bay in 1988.

We compared the 1988 presence of demersal nearshore species with those that we assume were present in the bay in 1877 (Table 6). These species lists should be considered as representative for their respective times, but not necessarily complete. Other species could have been present in the bay somewhere but not captured/observed for various reasons. With this in mind, we observe that less than half as many species were seen in the combined 1980s studies as were assumed present in 1877. The 1877 list was based on the assumptions that the bay conditions were still pristine and a species observed in adjacent Puget Sound nearshore waters could be present in Commencement Bay nearshore waters. In spite of the assumptions behind the species lists, the relative reduction in species, by half, suggests that there has been an impact on species diversity from the cumulative effects of habitat losses and other causes.

Clams

The implications of intertidal habitat reduced to 4% of its historic level are clear for clams and oysters. Before even considering other impacts to these groups, the physical elimination of so much habitat says nearly everything about their fate in Commencement Bay.

In those areas of habitat that remain, the waterways, some limited areas of mudflat in the vicinity of the waterways, and the north and south outer shores of the bay, species of clams still were present in 1988. Dames and Moore (1982) found _Macoma sp._, _Axinopsida serricata_, _Mytilus edulis_, _Pandora filosa_, _Tellina sp._, and _Transenell tantilla_ in and adjacent to two waterways. Blaylock and Houghton (1981) reported the following species collected at intertidal stations around the bay: _Macoma sp._, _Clinocardium californiense_, _Crytomya californica_, _Mytilus edulis_, _Protothaca sp._, _Solen sicarius_, _Tellina spp._, and _Transenella tantilla_. B. Harmon (Shoreline Community College, pers. comm.) led surveys in the bay, in 1988, and observed that butter clams were common at Brown's Point and oysters were absent on the Puyallup delta. The species reported during this period suggest that there may be little change in the diversity of species from 1877.

Sampling earlier in this period (Washington Pollution Control Commission 1950) at intertidal and some slightly greater depths provided a general description of clams present about 1950 (Table 6, below).

Table 6. Observations by Wash. Pollut. Control Comm. (1950).

Station	Observation
Off Pt. Defiance	Diverse invertebrates, including littleneck clam, bent-nose clam, _Astarte sp._, cockle
Off Ruston smelter	No visible organisms of any kind
Off south shore sewage discharge	Little or no marine life
Off mouth of City Waterway	Bent-nose and butter clams
Inside City Waterway	No visible living organisms
Off other waterway mouths	Bent-nose and small unident. clams
In Hylebos Waterway	Only bent-nose clams
North shore to Brown's Point	Bent-nose clams, and other marine life

Our review did not provide sufficient information on relative abundances of clams in intertidal areas in 1988. However, anecdotal information does give some indications. Many clam areas, including Commencement Bay, have been significantly filled by wood chips and woody debris (B. Harmon, Shoreline Community College, pers. comm.; B. Baldassin, Point Defiance Aquarium, pers. comm.). Due to contamination, the intertidal areas of Commencement Bay have been non-certifiable for commercial clam harvest "probably since the 1920s" (W. Cleland, Wash. Dept. Health, pers. comm.). A review of WDF harvest records showed no clams harvested in Commencement Bay since the beginning of the record, 1935 (L. Hoines, Washington Department of Fisheries, pers. comm.).

Crabs

The salt marsh habitat which was likely used by the purple beach crab and the hairy shore crab was virtually eliminated by 1988. Mudflats frequented by Dungeness crab, red crab, and spider crab were reduced to isolated islands of habitat adjacent to the mouth of the Puyallup River and to narrow sections along the north shore.

The eelgrass beds that disappeared from along the north shore inward from Brown's Point likely provided important habitat for various crab species, including Dungeness and red crab, cockles, and certain shrimps.

Salo and McComas (1980) reported on Dungeness crab observed by divers in Milwaukee Waterway. Blaylock and Houghton (1981) observed in infaunal core samples, Dungeness crab, hairy shore crab, a pea crab, the helmet crab, and unidentified immature stages. Dames and Moore (1982) sampled infauna in or around Middle and Milwaukee Waterways and reported finding hairy shore crab, immature Cancer sp., and unidentified immature stages. A more recent study in the waterways showed that Dungeness crabs were rarely observed, but rock crab apparently were more common (Tetra Tech, Inc. 1985).

None of the information reviewed provides a basis to estimate relative populations of crabs in the bay in 1988. Certain species such as the Dungeness and hairy shore crabs appeared to frequent most if not all of the remaining intertidal mudflat areas. Since 91% of the mudflats were eliminated, however, all crab production supported by that area was lost.

Shrimps

The intertidal mudflats that provided habitat for Callianassa Californiensis, a ghost shrimp, and Upogebia pugettensis, the blue mud shrimp, were reduced to 9% of the pre-development area, which reduced their populations proportionally. Recent studies in the bay have reported observations of incidental shrimps. Salo and McComas (1980) reported that divers observed numerous coonstripe shrimp on submerged (subtidal) debris in Milwaukee Waterway. Blaylock and Houghton (1981) observed ghost shrimp in core samples. Dames and Moore (1982) reported ghost shrimp and Upogebia pugettensis juveniles in infaunal core samples. Jones and Stokes (1989) also reported coonstripe shrimp in Milwaukee Waterway.

None of the information reviewed provides a basis to estimate relative populations of shrimps in intertidal habitats in 1988.

DISCUSSION

Changes in Populations and Distributions

The incremental, but near complete, loss of intertidal mudflat and salt marsh habitats has resulted in diminished populations of species of anadromous salmonids, demersal fish, clams, crabs, and shrimp. Large areas of lost habitat equate to certain losses of carrying capacities, either direct in the case of beds for clams or indirect in the case of forage and refuge for salmon and trout. Available information does not permit actual, meaningful estimates of existing population sizes of the animal groups. Population estimates were not available for any species prior to development of the bay. Given this lack of information, it is not possible to do more than state that nearly total loss of habitat resulted in nearly total loss of many species endemic to the bay during the 138 years prior to 1988.

Very clearly, the distribution of every species described above was severely reduced in a direct geographical relation to the specific habitat areas destroyed by conversion to non-aquatic, filled areas. Even the more mobile species of fish, which could likely avoid actual destruction of individuals by leaving a destoyed area, were restricted in their distribution as each area of habitat was lost.

One of our objectives, to determine the cumulative impact of all factors that have potentially affected intertidal fish and shellfish in Commencement Bay, has not been fully addressed. In addition to the gradual process of eliminating the intertidal habitats through dredging and filling, numerous other development-related processes/activities have been at work in the bay. Many industrial and commercial operations were (and still are) located in the filled areas of the bay , i.e., on the tideflats. These included pulp and lumber mills, shipbuilding, shipping, marinas, chlorine and chemical production, concrete production, aluminum smelting, oil refineries, food processing, automotive repair services, railroad operations, and a number of other storage, transportation, and chemical manufacturing companies. Waste management practices of these operations included direct and indirect discharges into the bay. Sewage, in different stages of treatment, and storm runoff were discharged into the bay. Approximately 480 point and nonpoint sources of contaminants empty into the bay nearshore waters (PTI Environmental Services 1989). The presence of these contaminant sources have had a range of effects on all life in the nearshore/intertidal habitat areas.

Other Impacts on Demersal Fish

Among the intertidal animal groups that we have addressed, perhaps none has been subject to cumulative impacts and studied as much as the demersal fishes, particularly the English sole. Flatfish spend much, if not all, of their time lying on the bottom substrate. They feed primarily on epibenthic/benthic organisms. Typically they have the total undersurface of their body in contact with the upper layer of bottom sediment. Any exposure of the sediments they lay on (or in) to toxic substances is likely to affect them. The same is true of most of their prey, since much of their preferred prey also exist in or on the same sediment layer.

Industrial activities, located along and between the waterways, and along the south shore of the bay, produced a broad array of substances that found their way into the waterways or open waters of the bay, either directly or indirectly. In addition to substances that originated at specific locations of industrial activity, toxic slag, a byproduct of the refinery at Ruston, was not only distributed along the south shore near the refinery, but was used widely as fill material in the tideflats area as recently as 1981 (Department of Ecology, unpubl. files). Metals in the slag were toxic to marine life. The slag was also used to produce commercial sandblasting material used widely in the tideflats area and used as building insulation.

Investigations of the contents in storm runoff from land areas that drain into bay waterways revealed very significant findings. At one site the estimated metals loadings (pounds per year) in runoff were: arsenic, 2500; zinc, 1100; copper, 510; lead, 310; nickel, 66; antimony, 50; and cadmium, 2. More loading, no doubt, reaches waterways via groundwater. Slag was considered the source of most of the metals. Recall that sampling by the Washington Pollution Control Commission (1950) found "no visible organisms of any kind" in nearshore areas on the south shore of the bay where slag was known to have been dumped. Over 30 years later, it was apparent from fish collections in the bay that fewer English sole were found in the vicinity of the shore area where effects of slag dumping occurred (Tetra Tech, Inc. 1985).

Investigations of Puget Sound water quality, performed from 1976 to 1985, involved, in part, identification of trends in contamination of sediments and English sole, Parophrys vetulus (Long 1988). Surveys around Puget Sound showed histopathological disorders in the fish were most prevalent in the urban harbors and waterways where sediments were most contaminated. The incidences of the most serious disorders, neoplasms of the livers, were most elevated in a few locations, including the industrial waterways of

Commencement Bay. In Middle Waterway, 40% of English sole had one or more liver lesions (Tetra Tech 1985).

Further studies of sediment toxicity showed that sediments in the Commencement Bay waterways were among the most toxic. Evidence from studies of liver disorders has provided a firm basis for the hypothesis that liver tumors and other idiopathic (of unknown cause) liver lesions in English sole are the result of exposure to sediment-associated chemical contaminants (Myers et al. 1988).

The tendency of English soles to have sediment-linked liver tumors is compounded by the fact that this species may be the most common, nearshore species of fish in Commencement Bay. Trawl collections in the bay waterways showed that English sole had the highest relative abundance, 55.6%, among a total 4951 fish sampled (Tetra Tech, Inc. 1985). Rock sole were the second most abundant. Apparently the habitat complexity in the waterways, i.e., pilings, rocks, and debris, helps to attract larger sole. Of possible concern was the unusually small proportion, 4%, of English sole in the bay samples that were smaller than 20 cm. This was attributed to the lack of suitable habitat, i.e., shallows with a sandy bed, for young sole. Another possible factor contributing to this apparent age imbalance is the absence of fishing pressure on sole and other fishes in the inner bay due to the human fear of eating diseased and toxic fish.

Other Impacts on Shellfish

The benthic macroinvertebrate assemblages, which includes clams, live in close contact with bottom sediments and are relatively stationary. They have a high potential for exposure to sediment contaminants in estuarine habitats. Contaminants found in the Tideflats area include arsenic, lead, zinc, cadmium, copper, mercury, and a variety of organic compounds such as polychlorinated biphenyls (PCB) and polycyclic aromatic hydrocarbons (PAH) (PTI Environmental Services 1989). Sediments in all parts of the nearshore/tideflats area contain concentrations of one or more toxic contaminants that exceed levels commonly found in Puget Sound reference areas (controls). Four inorganic and six organic contaminants were detected at concentrations 1000 times as great as reference conditions. These were found near the Ruston-Point Defiance Shoreline, at Hylebos Waterway, and the St. Paul Waterway. Twenty-eight chemical or chemical groups had concentrations 100 to 1000 times as great as reference conditions. Most of the contamination of sediments likely occurred during this period, i.e., since 1941. Sediments in the bay containing increased levels of organic contaminants were less than 25 years old (Riley et al. 1981).

Waterway sediments supported fewer benthic macroinvertebrate species than other bay areas, indicating generalized effects from contamination (Tetra Tech 1985). Typical benthic assemblages in the waterways were dominated by polychaete worms and small clams, suggesting reduced diversity due to adverse habitat conditions.

Cumulative Impacts

We have described in detail the gradual process of habitat loss that occurred in the inner bay and along the south shoreline. The gradual impact on the fish and shellfish that relied on those habitats was described as well. The more or less simultaneous and continually expanding (over time) impacts of numerous contaminants from human activities caused a cumulative impact on fish and shellfish, if not the entire food web present. For example, the bent-nose clam, Macoma nasuta, still existed in the waterway remnants of their former expanse of mudflat habitats; however, the number of individuals observed within waterways declined to zero as sampling approached certain hotspots of contamination (Tetra Tech 1985) or approached the upper ends of blind waterways lacking any water circulation (in combination with contaminated sediments)(Wash. Pollut. Control Comm. 1950). This is an example of cumlative negative impact. Other examples of cumulative negative impact: those waterway locations where contaminated runoff from smelter-generated fill reduced diversity of benthic life and numbers of most species expected there; the intertidal areas devoid of marine life where smelter slag was dumped along the south shore, at once eliminating the preexisting beach and contaminating the habitat severely.

Habitat of Special Significance

All areas of destroyed intertidal mudflat, vegetated shallows, and salt marsh in Commencement Bay were of great value as habitat for the species adapted to them. Just as vital to all assemblages of aquatic species was the high quality of the water itself, free of unnatural contaminants. As we have described, some species relied on the mudflat and its particular conditions for foraging at various levels in the food web and as a medium for burrowing. Similarly, the salt marsh served as habitat and refuge for various species, and a major source of organic detritus supporting the food web. The other special aquatic habitat, eelgrass, while not as abundant in area, was important for its characteristic source of refuge on the border of the intertidal zone and the subtidal zone.

While the three special aquatic habitat types all have their own values, we agreed to attempt to identify candidate areas of greater value for purposes of future protection/restoration. The following are our recommendations.

1. Protect all remaining special aquatic habitat areas.

2. Enhance and extend the mudflats that have formed naturally off both banks of the mouth of the Puyallup Waterway. Extend them in a manner that maximizes possible intertidal surface area when submerged.

3. Restore the eelgrass beds that formerly existed along the north shore, from at least opposite Brown's Point to at least 2 miles inward along the north shoreline.

4. Restore eelgrass beds from opposite Point Defiance and continuously inward along the south shoreline as far into the bay as the bed characteristics are suitable. This should include all of the reach that was subject to impacts from slag deposition.

5. Reclaim and restore additional areas of the filled mudflat/salt marsh in a manner similar to that performed at the Gog-le-hi-te wetland. These wetlands should not have a functional area of less than 10 acres (Thom et al. 1990).

6. Reclaim and restore areas of freshwater wetland, linked by continuous access to the mainstem Puyallup River.

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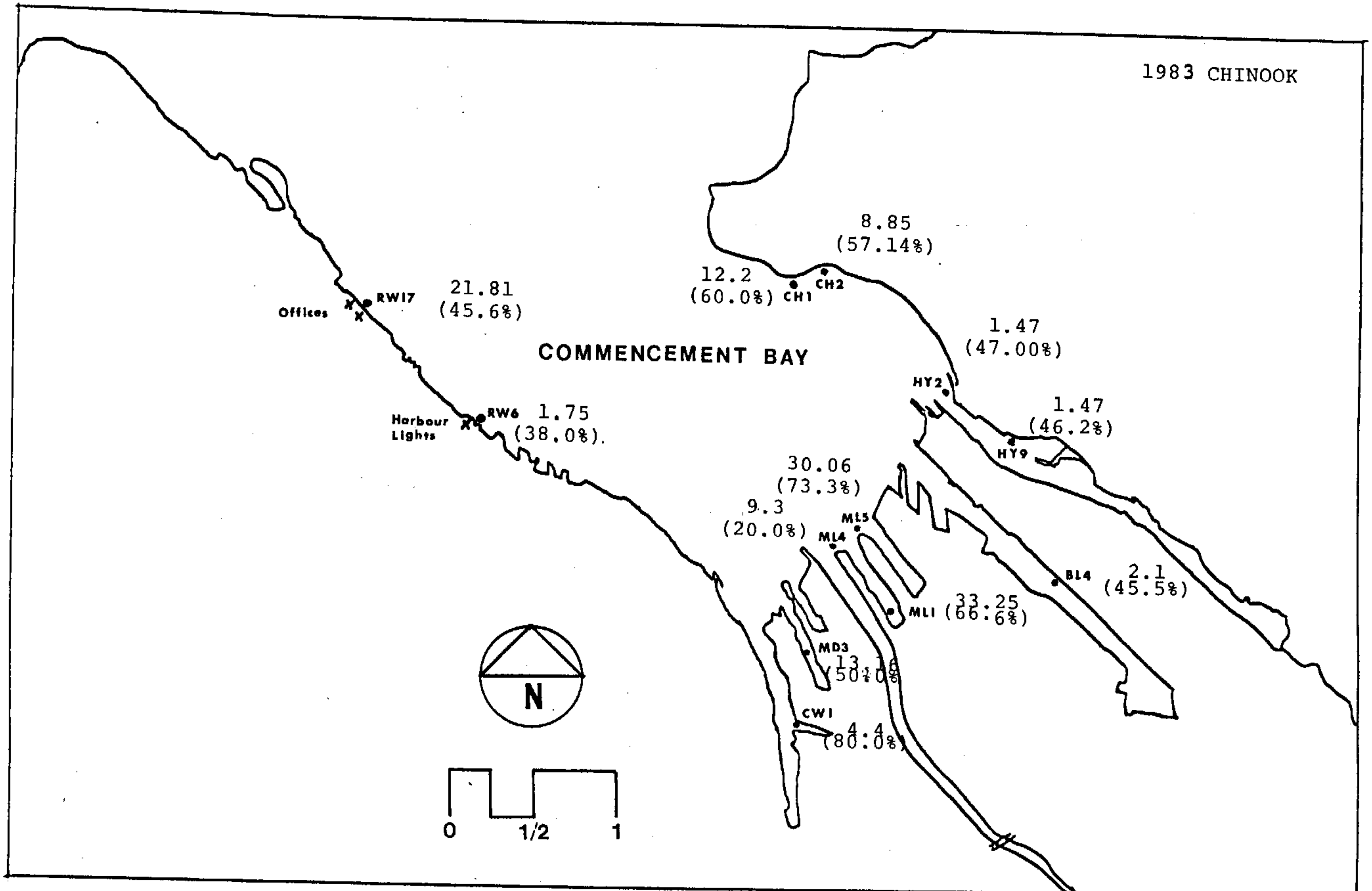

Figure 9.. Puyallup Tribe standard beach seine sampling locations.

Table 1. Information documenting presence of anadromous salmonids in Commencement Bay.

Year	Source	Excerpt
1940	Smith, M. W.	1) (Numerous descriptions of Indian methods of capturing salmon in Puyallup River and in Commencement Bay) 2) "Salmon were plentiful and could be caught in the Sound at any time of year, but the great catches were made at large fish traps set across streams and operated when the salmon came up into fresh water to spawn . . ."
1981	Lane and Lane Assoc. et al.	1) "At treaty times the Puyallup [Indians] had a number of weirs across the maintstem Puyallup and tributary streams which were capable of stopping virtually all anadromous fish . . . the food staple and the basis of Puyallup economy at treaty times [1854]. The Puyallup harvested chinook, coho, pink and chum salmon as well as steelhead trout in the Puyallup River system and in the adjacent marine waters." 2) "At treaty time the Muckleshoot [Indians] had weirs on the White and Stuck rivers and . . . had the capability of harvesting . . . anadromous fish during the spawning runs. Like the Puyallup, the Muckleshoot took only those fish needed for subsistence and ceremonial use and for trade." 3) "Prior to ascending the Puyallup for spawning purposes, fish milled about in Commencement Bay where Puyallup Indian fishermen and neighboring upper Puget Sound people harvested them by trolling from canoes. In addition, Puyallup Indians took considerable numbers of these fish in beach seine operations." 4) "It is astonishing how abundant these salmon are found in the small streams and even rivulets of the headwaters of the greater rivers below . . [in the Puyallup system]"
1916	Hunt, H.	1) [1853-55] At a point between Old Tacoma and the smelter, seining for salmon was so successful that it supported shipping barrels of salted salmon to San Francisco 2) [1868] A fishing "camp" located at Old Tacoma ". . . had been making great hauls--2000 fine salmon in one seining . . . their annual pack amounted to from two to four thousand barrels."

Table 2. Demersal fish species prevalent in Pacific Northwest estuarine channels. From Simenstad (1983).

Taxa	Common name
CYPRINIDAE	
Mylocheilus caurinus	Peamouth
GADIDAE	
Microgadus proximum	Pacific tomcod
EMBIOTOCIDAE	
Cymatogaster aggregata	Shiner perch
STICHAEIDAE	
Lumpenus sagitta	Snake prickleback
AMMODYTIDAE	
Ammodytes hexapterus	Pacific sand lance
COTTIDAE	
Cottus asper	Prickly sculpin
Leptocottus armatus	Pacific staghorn sculpin
BOTHIDAE	
Citharichthys sordidus	Speckled sanddab
PLEURONECTIDAE	
Parophrys vetulus	English sole
Platichthys stellatus	Starry flounder

Table 3. Frequency of occurrence of fish species in collections made at Commencement Bay and estuary (CB), Nisqually River delta and estuary (ND), and Quartermaster Harbor (Q), in Puget Sound, Washington. From B. Miller and S. Borton (1980). NS = inhabits nearshore, OS = inhabits offshore, D = predominantly demersal, and P = predominantly pelagic. Year = earliest year of collection.

Species name	Common name	Dominant Habitat	Frequency of occurrence//Year		
			CB	ND	Q
Lampetra tridentatus	Pacific lamprey	D,NS	1 /1942	0	
Squalus acanthias	Spiny dogfish	D,NS	Many/1940	0	6 /1950
Clupea harengus pallasi	Pacific herring	P,NS	1 /1938	1 /1973	Many/1941
Oncorhynchus gorbuscha	Pink salmon	P,NS	Many/1937	Many/1969	
Oncorhynchus keta	Chum salmon	P,NS	Many/1954	Many/1946	
Oncorhynchus kisutch	Coho salmon	P,NS	Many/1953	Many/1954	
Oncorhynchus nerka	Sockeye salmon	P,NS	1 /1929	10 /1972	
Oncorhynchus tshawytscha	Chinook salmon	P,NS	Many/1862	Many/1954	
Hypomesus pretiosus	Surf smelt	P,NS	3 /1938	0	
Notorynchus maculatus	Sevengill shark	D,OS	0	1 /1863	
Oncorhynchus clarki	Cutthroat trout	P,NS	0	Many/1972	Many/----
Oncorhynchus mykiss	Rainbow trout	P,NS	0	Many/1972	
Thaleichthys pacificus	Eulachon	P,NS	12 /1976	0	
Gasterosteus aculeatus	Threespine stickleback	P,NS	0	10 /1973	
Cymatogaster aggregata	Shiner perch	D,NS	1 /----	Many/1937	4 /1950
Icosteus aenigmaticus	Ragfish	P,OS	1 /1960	0	
Ophiodon elongatus	Lingcod	D,NS	Many/1940	0	1 /1894
Chitonotus pugetensis	Roughback sculpin	D,NS	0	12 /1937	1 /1967
Artedius harringtoni	Scalyhead sculpin	D,NS	0	1 /1973	
Artedius fenestralis	Padded sculpin	D,NS	0	7 /1972	
Clinocottus acuticeps	Sharpnose sculpin	D,NS	0	10 /----	
Enophrys bison	Buffalo sculpin	D,NS	0	1 /1973	
Icelinus borealis	Northern sculpin	D,NS	0	1 /1963	
Leptocottus armatus	Pacific staghorn sculpin	D,NS	0	Many/----	
Nautichthys oculofasciatus	Sailfin sculpin	D,NS	0	2 /1963	
Oligocottus maculosus	Tidepool sculpin	D,NS	0	2 /----	
Agonopsis emmelane	Northern spearnose poacher	D,NS	0	1 /1973	
Agonus acipenserinus	Sturgeon poacher	D,NS	0	3 /1973	
Odontopyxis trispinosa	Pygmy poacher	D,NS	0	3 /1973	
Xeneretmus latifrons	Blacktip poacher	D,NS	0	1 /----	1 /1967
Liparis pulchellus	Showy snailfish	D,NS	0	1 /----	
Citharichthys stigmaeus	Speckled sanddab	D,NS	0	7 /1963	
Hippoglossoides elassodon	Flathead sole	D,NS	1 /1882	0	2 /1950
Hippoglossus stenolepis	Pacific halibut	D,OS	0	1 /1940	Many/1940
Isopsetta isolepis	Butter sole	D,NS	0	5 /1973	
Lepidopsetta bilineata	Rock sole	D,NS	0	Many/1937	4 /1942
Microstomus pacificus	Dover sole	D,NS	0	1 /----	5 /1950
Parophrys vetulus	English sole	D,NS	0	Many/1937	5 /1950
Platichthys stellatus	Starry flounder	D,NS	0	15 /1973	2 /1950
Pleuronichthys coenosus	C-O sole	D,NS	0	5 /1973	
Psettichthys melanosticus	Sand sole	D,NS	0	10 /1973	
Raja binoculata	Big skate	D,NS	0	2 /1950	2 /1950
Hydrolagus colliei	Ratfish	D,NS	0	3 /1973	8 /1937
Porichthys notatus	Plainfin midshipman	D,NS	0	2 /1937	1 /1950

Table 3. (continued)

Species name	Common name	Dominant Habitat	Frequency of occurrence/year					
			CB		ND		Q	
Microgadus proximus	Pacific tomcod	D,NS	0		3	/1973	4	/1950
Syngnathus griseolineatus	Bay pipefish	D,NS	0		3	/1973		
Embiotoca lateralis	Striped seaperch	D,NS	0		8	/1973		
Rhacochilus vacca	Pile perch	D,NS	0		2	/1973	2	/1951
Lumpenus sagitta	Snake prickleback	D,NS	0		1	/1973	2	/1950
Pholis laeta	Crescent gunnel	D,NS	0		2	/1973		
Pholis ornata	Saddleback gunnel	D,NS	0		4	/1973		
Sebastes auriculatus	Brown rockfish	D,NS	1	/1972	3	/1973		
Sebastes caurinus	Copper rockfish	D,NS	0		1	/----	2	/1950
Sebastes maliger	Quillback rockfish	D,NS	2	/----	1	/1973	3	/1937
Apristurus brunneus	Brown cat shark	D,OS					1	/----
Anoplopoma fimbria	Sablefish	D,OS					3	/1951
Hexagrammos stelleri	White spotted greenling	D,NS					1	/1951
Radulinus asprellus	Slim sculpin	D,NS					4	/1950
Citharichthys sordidus	Pacific sanddab	D,NS					3	/1950
Atheresthes stomias	Arrowtooth flounder	D,NS					3	/1950
Eopsetta jordani	Petrale sole	D,NS					1	/1951
Glyptocephalus zachirus	Rex sole	D,NS					4	/1950
Lyopsetta exilis	Slender sole	D,NS					5	/1950

Table 4. Information supporting the assumption regarding presence of clams in Commencement Bay prior to industrialization.

Year	Source	Excerpt
1852	Hunt, H. 1916	1) ". . . the long sloping beach about the head of the bay was white with the clam shells of unnumbered [Indian] banquets."
1868		2) "A large group went to Brown's Point on the fourth of July and all enjoyed clams there."
1873	Lane, B. 1984	Quoting Milroy (March 20, 1873): " . . . the exhaustless clam beds at low water, along the shore of the Bay nearly a mile south of the mouth of the Puyallup and for over two miles north of the marshes of that river . . ."

Table 5. Cumulative changes in area of special aquatic site habitat and corresponding increases in area filled in Commencement Bay and estuary, Tacoma, Washington. Areas are in acres.

	Special aquatic site habitat		
Year	Intertidal mudflat	Intertidal emergent marsh	Filled areas
Pre 1877	2085	3894	
1894	2074	3874	
1907	1469	3459	870
1917	927	3395	1413
1927	765	3320	1532
1941	632	1644	1869
1988	187 *	57 **	5005

* Intertidal mudflat-E2US3N

** Emergent marsh - PEM1

Table 6. Nearshore demersal fishes presumed to be present in Commencement Bay in 1877, and nearshore demersal fishes observed in Commencement Bay since 1980.

Species name	Common name	Presence in bay	
		1877 *	Since 1980 **
Sebastes auriculatus	Brown rockfish	X	
Sebastes caurinus	Copper rockfish	X	X
Sebastes maliger	Quillback rockfish	X	
Scorpaenichthys maramoratus	Cabezon	X	X
Cymatogaster aggregata	Shiner perch	X	X
Rhacochilus vacca	Pile perch	X	X
Embiotoca lateralis	Striped seaperch	X	X
Mylocheilus caurinus	Peamouth	X	
Ammodytes hexapterus	Pacific sand lance	X	X
Ophiodon elongatus	Lingcod	X	
Hexagrammos stelleri	White spotted greenling	X	X
Hexagrammos decagrammus	Kelp greenling	X	
Chitonotus pugetensis	Roughback sculpin	X	
Artedius harringtoni	Scalyhead sculpin	X	
Artedius fenestralis	Padded sculpin	X	X
Clinocottus acuticeps	Sharpnose sculpin	X	
Enophrys bison	Buffalo sculpin	X	X
Icelinus borealis	Northern sculpin	X	
Leptocottus armatus	Pacific staghorn sculpin	X	X
Nautichthys oculofasciatus	Sailfin sculpin	X	
Oligocottus maculosus	Tidepool sculpin	X	X
Radulinus asprellus	Slim sculpin	X	
Myoxocephalus polyacanthocephalus	Great sculpin	X	
Psychrolutes paradoxus	Tadpole sculpin	X	
Oligocuttus rimensis	Prickly sculpin	X	
Agonopsis emmelane	Northern spearnose poacher	X	
Agonus acipenserinus	Sturgeon poacher	X	X
Odontopyxis trispinosa	Pygmy poacher	X	
Xeneretmus latifrons	Blacktip poacher	X	
Liparis pulchellus	Showy snailfish	X	
Citharichthys stigmaeus	Speckled sanddab	X	X
Citharichthys sordidus	Pacific sanddab	X	X
Hippoglossoides elassodon	Flathead sole	X	X
Isopsetta isolepis	Butter sole	X	
Lepidopsetta bilineata	Rock sole	X	X
Microstomus pacificus	Dover sole	X	X
Parophrys vetulus	English sole	X	X
Eopsetta jordani	Petrale sole	X	
Glyptocephalus zachirus	Rex sole	X	
Lyopsetta exilis	Slender sole	X	
Pleuronichthys coenosus	C-O sole	X	X
Psettichthys melanosticus	Sand sole	X	X
Platichthys stellatus	Starry flounder	X	X
Atheresthes stomias	Arrowtooth flounder	X	

Table 6. (continued)

Species name	Common name	Presence in bay	
		1877 *	Since 1980 **0 **
Microgadus proximus	Pacific tomcod	X	
Pholis laeta	Crescent gunnel	X	X
Pholis ornata	Saddleback gunnel	X	
Apodichthys flavius	Penpoint gunnel	X	
Lepidogobius lepidus	Bay goby	X	
Porichthys notatus	Plainfin midshipman	X	X
Lumpenus sagitta	Snake prickleback	X	X
Syngnathus griseolineatus	Bay pipefish	X	X
Squalus acanthias	Spiny dogfish	X	
Raja binoculata	Big skate	X	
Hydrolagus colliei	Ratfish	X	X
Lampetra tridentatus	Pacific lamprey	X	

Source: * Miller and Borton (1980); Simenstad (1983); DeLacy et al. (1972)

** Weitcamp and Schadt (1981); Jones and Stokes Associates (1989); Salo and McComas (1980); Thom et al. (1990).