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A REVIEW OF THE LITERATURE ON THE VALUE OF ESTUARINE AND SHORELINE AREAS TO JUVENILE SALMONIDS IN PUGET SOUND, WASHINGTON

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A Review of the Literature
On the Value of Estuarine and Shoreline Areas
To Juvenile Salmonids in Puget Sound, Washington

Problem Statement

An attempt has been made to review the most current and pertinent literature plus on-going research pertaining to the role and importance of estuarine and shoreline areas to juvenile salmonids. Also included is a brief review of the impacts on salmonids of alterations to these areas. Primary emphasis was placed on salmonids because of their importance to Pacific Coast fisheries.

The U.S. Fish and Wildlife Service (FWS), as the federal agency responsible for preserving, protecting, and enhancing fish and wildlife resources, is greatly concerned with protection of estuarine and shoreline areas. FWS responsibilities for these areas are mandated by the Fish and Wildlife Coordination Act, Migratory Bird Treaty Act, Endangered Species Act, Anadromous Fish Act, and National Environmental Policy Act. As the protector and manager of fish and wildlife habitat, the FWS needs information regarding the importance of estuarine and shoreline areas to all forms of fish and wildlife plus an understanding of the biological impacts which result when these ecosystems are altered.

The value of estuarine areas to fishery resources on the eastern and southern coasts of the United States is well documented. Estuaries and shallow shorelines also have considerable value as habitat for various forms of wildlife, esthetic and recreational importance, and are areas of high primary productivity and nutrient cycling. However, knowledge of the role played by these ecosystems on the west coast is much more limited, particularly as they relate to fish.

Considerable work has been directed toward problems affecting survival during the freshwater period in the life history of most salmonids. Much less is known about the estuarine and early marine phases despite an apparent widely fluctuating high mortality that probably has a significant impact on ultimate survival and adult returns. Recently, several authors have begun to recognize the early nearshore period as being important to overall survival. Work by Parker (1968) on pink salmon from the Bella Coola River in British Columbia indicated a high initial natural mortality of 2-4% per day for the first 40 days of inshore marine life. Mortality during the next 410 days of oceanic life decreased to .4-.8% per day. Studies by LeBrasseur and Parker (1964) on the same stock of fish showed that "...growth was approximately exponential during an initial 40 day period. Fish increased in length from 3.5 to 8.4 cm. Thereafter, the instantaneous rate of growth gradually declined." Royal (1962) points to the early marine life as a critical stage for Fraser River sockeye while Mathews and Buckley (1976) come to a similar conclusion for Puget Sound coho. Schreiner (1977) states, regarding Hood Canal chum salmon, "...a growing amount of evidence suggests that though fry mortality is extremely high in freshwater stages, population variability in survival and growth may be correlated best with environmental conditions during the early marine phase of the salmonid life cycle."

Another aspect of considerable interest recently is the possible upper limit to estuarine and nearshore rearing capacity and the ability of these areas to support greatly increased numbers of artificially reared juveniles. Tremendous interest has been directed toward artificial enhancement of salmon and steelhead as a result of an increasing demand for a limited resource. Many see enhancement as the answer to declining stocks and plans for increased releases of anadromous fish are being formulated for many areas of the Pacific Coast. Greatest emphasis in most of these enhancement efforts is being placed upon chum salmon. Releases of artificially reared chums in Puget Sound has risen from just over 8 million in 1970 to nearly 57 million in 1977. The Washington Department of Fisheries (WDF) has received funding for enhancement programs that could produce an additional 165 million chum fry in Puget Sound alone. These plans are proceeding on the assumption that an increase in salmonid smolts or fry entering the marine environment will result in a proportionate increase in returning adults. While the Pacific Ocean may well be capable of rearing larger numbers of fish than it is presently supporting, the rearing capacity of the estuarine and nearshore areas may be limited and this capacity may have been seriously impacted by various forms of degradation.

In order to preserve present production and options for future enhancement of Puget Sound salmon and steelhead, it is necessary to better understand the ecological role and possible limitations imposed by freshwater, estuarine and oceanic environments. Although there are questions remaining regarding the freshwater phase, much work has been and is being, directed toward this period in the salmonid life history. Oceanic investigations present numerous difficulties and may best be addressed by other agencies with appropriate responsibilities. Based upon the evidence presented in the literature regarding the importance of the estuarine and nearshore environment to fishery resources in other areas, there is an immediate need to investigate these ecosystems and their contribution to Puget Sound salmonid production and survival. In addition, habitat managers must have the ability to predict impacts on salmonids and their prey resources resulting from further estuarine and shoreline alteration.

Salmonid Utilization of Estuarine and Shallow Shoreline Areas

Estuaries on the southern and eastern coasts of the continental United States have been shown to be important nursery/rearing areas for numerous economically important species of fish. The trophic relationships existing in these estuaries have generally been shown to depend to a large degree upon in-puts of organic detritus from the associated salt marsh (Teal, 1962; Nixon and Oviatt, 1973; Naiman and Sibert, 1979). Salt marshes throughout the world, including those found on the west coast of the United States, have been found to be highly productive systems (Teal, 1969; Klotz et. al., 1978). Klotz et. al. (1978), in their survey of the Nisqually Delta in southern Puget Sound, review several marsh productivity studies which indicate that salt marshes on the west coast of the United States probably have productivity rates comparable to those found on the east coast.

In 1977, Sibert et. al. showed a link between chum salmon in the Nanaimo River estuary in British Columbia and a detritus-based food web. They identified four sources of detritus in the Nanaimo estuary as: 1) Zostera spp. meadows from the seaward areas; 2) algae from the intertidal areas; 3) Carex spp. marsh from the landward areas, and 4) downstream transport from the upland areas of the watershed. The relative contribution of each of these sources was not evaluated in their studies. In 1979, Naiman and Sibert conducted one of the few Pacific Coast estuarine carbon flow studies, in the Nanaimo estuary. They measured the productivity of Zostera meadows, phytoplankton, epibenthic algae, macroalgae, and the organic load of the Nanaimo River. Productivity of the salt marsh was not actually measured and average values from nearby marshes were used. The investigators concluded that "river transport of FPOC (fine particulate organic carbon) is twice the estimated Zostera production and exceeds the combined production of macroalgae, epibenthic microalgae, and phytoplankton. The marsh has the potential to supply large amounts of carbon but is poorly flooded by high tides and may not contribute much to the intertidal area." The authors do, however, conclude that the timing of the various carbon sources is important; "It is evident that each carbon source becomes important to consumer species by its timing in availability to the food web, and not just through the magnitude of its input."

Probably the first extensive study of the estuary's salt marsh as salmonid habitat, was by Dunford (1975) who examined the Fraser River estuary in British Columbia. Two types of habitat were examined: sloughs and side channels. Sloughs were defined as areas exposed to the flow of the river and side channels as blind channels leading into the salt marsh. The amount of water in side channels, which were often dewatered at low tide, was governed by tidal height and level of river discharge. Both areas were examined to determine if salmonids were residing there for any length of time, and if so, what food organisms were being consumed. Dunford (1975) states, "Growth of juvenile salmon before they encounter sea water most probably will enhance their marine survival, and for this reason the estuarine feeding is of great importance."

The two most prevalent species encountered in Dunford's (1975) study were chum and chinook fry. Chum arrived first (mid-March) and were most abundant initially. Numbers of chinook juveniles began building up soon after and were the most abundant species by late April. At this point, abundance of both species began to decline. Chum were present through mid-June; chinook were present into August. Chum sampled during this study averaged 37-38 mm from March through late May indicating only a brief residency and growth in the study area. Chinook, on the other hand, averaged 39-40 mm through April but increased thereafter until they left the estuary. The increase in average fork length indicated fairly rapid growth.

In the slough habitat, Dunford (1975) found that the species composition of the diet of both chum and chinook changed with time possibly in response to the availability of prey items. He also found statistical differences in prey size. Important food items in chum stomachs at various times were chironomid pupae and larvae, cladocera (Daphnia), Anisogammarus and Corophium amphipods, and Neomysis. Included was Corophium spinicorne, and estuarine species; other groups were only identified to genus and it is assumed they were estuarine forms. Items of importance to chinook were chironomid pupae, Anisogrammarus and Corophium amphipods, and Neomysis. Dominant food items in chum stomachs from the side channel habitat were similar to those in the slough habitat except that harpacticoid copepods and Collembola (a semi-aquatic insect) became very important components of the diet. Chinook prey items from side channels were also similar to those in the slough except that Collembola again became fairly important. Dunford (1975) determined that chironomid pupae and Daphnia were preferred food items for both species.

Stomach contents of yearling chinook were also examined and found to contain significant numbers of chum fry plus chironomid pupae and Daphnia.

Based upon his study findings, Dunford (1975) concluded that "... the slough and side channel habitats of the Fraser River estuary have been shown to be important feeding areas for juvenile chum and chinook salmon."

Sibert (1975) conducted tagging studies in the vicinity of British Columbia's Nanaimo River to determine the length of residency of juvenile chinook in the estuary and surrounding shallow nearshore areas. He found some individual fish remained in that estuary up to 2 months.

Additional studies of the Nanaimo estuary were conducted by Sibert et. al. (1977). This work, which concentrated on chums in the tidal flats and sloughs, indicated that in March and April individual chums spent 13-18 days in the study area and that fish from the latter portion of the out-migration period spent less time in the estuary (1.5 days). The dominant food item was identified as harpacticoid copepods. Growth rates were estimated to be 4% per day. Based upon the numbers of food organisms present, the investigators estimated the carrying capacity of this estuary to be 22 times the number present in the year in which this study occurred. The authors concluded that, "These fish spend the first critical weeks of their sea life in river mouths and along beaches feeding on harpacticoids and other small benthos. The food of the harpacticoids is the bacterial flora associated with organic detritus."

Levy and Levings (1978) examined the food habits of salmon in another British Columbia estuary at the mouth of the Squamish River. They determined that important prey items of chum were insect pupae and larvae, Anisogammarus amphipods, cyclopoid and harpacticoid copepods, and Neomysis; chinook were feeding predominately on Neomysis. From their findings in the Squamish estuary, the authors identify the following estuarine organisms as important prey items to chum, chinook, coho, pink, cutthroat and Dolly Vardon: Neomysis mercedis, Anisogammarus confervicolus, Corophium spinicorne, Gnorimosphaeroma oregoresis (an isopod), and Crangor sp.

Investigations of the Nanaimo River estuary were continued by Healey (1979) and expanded the scope of the earlier work by Sibert et. al. (1977). Healey (1979) again found variations in residence time of juvenile chum in the estuary following out-migration from the Nanaimo River. Residency times over the two year study ranged from 0-18 days. He found fry scattered along the margins of the delta at high tide dropping back into tidal creeks and stream channels along the east side of the delta at low tide. Favored areas were quiet backwaters adjacent to deeper water, sandy sediments, and areas in which eelgrass was present.

The most common food item was again identified as harpacticoid copepods. During the peak out-migration period, they made up over 80% of the diet. In contrast to the earlier findings of Sibert et. al. (1977), stomach contents showed a decrease in biomass during the peak out-migration period, possibly indicating a shortage of the preferred food item.

Healey (1979) also identified 15 different species or species complexes of harpacticoid copepods as contributing to chum fry diets. Of these 15 species, Harpacticus uniremis greatly outnumbered the others in chum stomachs. This occurred despite the fact that it was considered uncommon compared to the other species of harpacticoids found in the Nanaimo estuary (Sibert, 1979). Seasonal chum fry abundance corresponded to the seasonal abundance of H. uniremis and, in addition, chum fry emigration from the estuary occurred as the H. uniremis population decreased. It was also determined that the fry consumed a high proportion of the available H. uniremis population. Therefore, Healey (1979) felt that residence time of chum fry in the Nanaimo estuary was linked to this particular species of copepod. However, he also points out that while H. uniremis was present on both the east and west margins of the delta, concentrations of chum fry were only found on the east side at low tide indicating that other factors besides the presence of the preferred food item are critical in fry distribution and residence in the estuary.

Merril and Koski (1978) examined the stomach contents of cutthroat, coho, steelhead and Dolly Varden in a small stream in Alaska. They found these fish feeding on epibenthic invertebrates in the "stream/estuary ecotone." They also determined that this ecotone produced eight times as many prey organisms as the "stream/forest ecotone." They concluded that the stream/estuary ecotone was a significant nursery area for stream salmonids.

Probably the most conclusive study to date on the importance to juvenile salmonids of estuarine residence is the work of Reimers (1971) on fall chinook in the Sixes River in Oregon. Five different juvenile life history patterns were identified for fall chinook in the Sixes River. Differences in life history related to the amount of time spent in freshwater and the estuary prior to entry into the ocean. The most common life history pattern consisted of those juveniles which remained in the main river and tributaries until early summer, then moved into the estuary experiencing rapid growth until mid-summer when the highest abundance of juveniles occurred. During the mid-summer period of greatest abundance in the estuary, growth slowed or stopped and at this point, the majority of the estuary's juvenile chinook entered the ocean. The second most common life history type were those juveniles which entered the estuary in early summer and remained there through the mid-summer period of decreased growth until late summer and early fall when growth again became quite rapid. The five life history types were identified in adults from scale patterns. From samples of spawning fish throughout the Sixes River, Reimers (1971) found that 90.6% of the spawning population was composed of fish which, as juveniles, had resided in the estuary throughout the summer and had experienced the rapid growth period in the fall (the second most common juvenile life history type). Apparently the overall survival costs of remaining in the estuary during the mid-summer period of reduced growth were much less than those of early entry into the ocean.

The only investigation in Puget Sound regarding the importance of the salt marsh plus its tidal creeks and sloughs to salmonids, is the on-going study of Congleton (1976). His work concerns the diet composition, feeding areas, feeding chronology and residence time of juvenile salmonids in the Skagit River marsh in northern Puget Sound. Juvenile chum and chinook have been found to spread out over the Skagit tidal flats at high tide with a concurrent increase in feeding activity. As the tide recedes, the fish move back into water filled creeks and channels. Dominant prey items from sampling in 1977 and 1978 were dipteran adults and pupae which comprised 58-81% of the diet by weight. Other important items were harpacticoid copepods and Anisogrammus confervicolus, an estuarine amphipod. In discussing the importance of the timing of salmonid out-migration and the availability of prey populations, Congleton (personnel communication) points out that the numbers of prey organisms in the Skagit marsh begin to build up by late March, which is prior to significant increases in the epibenthic population (principally harpacticoid copepods) in Skagit Bay. Therefore, the marsh may act as a food reservoir for juvenile salmonids prior to the build-up of other invertebrate populations. An early conclusion of this study is that the Skagit marsh is an important foraging area for juvenile chum and chinook.

Early investigations of juvenile salmon distribution and food habits during the early marine period indicated that feeding was directed toward pelagic zooplankton. However, most of these early studies were conducted in deep water areas some distance from shore. Gerke and Kaczynski (1972) made the first detailed study of pink and chum salmon diets in Puget Sound during the inshore period. They found that juvenile pink and chum in southern Puget Sound were feeding almost exclusively on epibenthic invertebrates. Harpacticoid copepods in particular comprised 95% of the food items from fish sampled at Anderson Island. Fish sampled in northern Puget Sound and Hood Canal contained fewer epibenthic organisms, but still comprised a significant portion of the diet.

Later works in Puget Sound by Feller and Kaczynski (1975) and Kaczynski et. al. (1973) confirmed the importance of epibenthic organisms in the diet of pink and chum fry during their migration along shorelines. The work by Kaczynski et. al. (1973) confirms selective feeding on harpacticoid copepods. Diet studies in other areas have also shown the importance of epibenthic organisms as an early prey item for juvenile salmon. Studies in the Columbia River estuary, San Francisco Bay, Tillamook Bay and Grays Harbor (Lipovsky, 1977; Sasaki, 1966; Forsberg et. al., 1977; and Herman, 1971) indicate that epibenthic amphipods are particularly important. Studies in British Columbia by Mason (1974), Sibert et. al. (1977), and Healey (1979) have pointed to epibenthic organisms, including harpacticoid copepods, as an important food resource. Harris and Hartt (1977) identified the numerous bays and inlets of Kodiak Island, Alaska as an important nursery area for many species of fish including pink and chum salmon plus Dolly Varden char. Harris and Hartt (1977) examined the stomach contents of these species, and as expected, the pink and chum were feeding principally on epibenthic invertebrates while in shallow inshore areas. It is also interesting to note from this study that Dolly Varden were feeding heavily on gammarid amphipods, which comprised their most frequently occurring prey item but were second in terms of total biomass behind sand lance.

Recent work in Puget Sound by Miller et. al. (1977), Fresh et. al. (1978), Schreiner et. al. (1977), Simenstad and Kinney (1978) and Bax et. al. (1978) have added further to our knowledge of the inshore migration period.

Fresh et. al. (1978) investigated the distribution and feeding habits of marine fishes in the vicinity of the Nisqually Reach in southern Puget Sound. Besides finding a heavy utilization of epibenthic invertebrates by chum fry, they also determined that epibenthic organisms comprised a significant percentage of the diet of juvenile coho and chinook. Coho sampled with beach seines contained high numbers of gammarid amphipods, cumaceans, flabelliferan isopods, harpacticoid copepods and mysids. Coho caught with townets in deeper water contained high numbers of pelagic species such as euphausiids and ostracods plus fewer numbers of benthic organisms. The authors of this study suggest that coho may be feeding in shallow inshore areas during daylight hours and in deeper neritic waters at night. Juvenile chinook captured with both beach seines and townets also contained high numbers of epibenthic organisms (gammarid amphipods, mysids, cumaceans, shrimp (Crangon sp.) and harpacticoid copepods). A somewhat surprising finding in this study was the high numbers of pelagic organisms (calanoid copepods and larvaceans) in pink salmon stomachs. Although epibenthic prey were also present, they represented a less important prey item from both townet and beach seine samples.

The extensive studies of Schreiner et. al. (1977), Bax et. al. (1978) and Simenstad and Kinney (1978) provide further insight into the early food habits and distribution of juvenile chums in particular. These studies were conducted in the shallow inshore and deeper neritic zones of northern Hood Canal. A common finding of all of these studies is the heavy utilization by chum fry of harpacticoid copepods and other epibenthic organisms in the shallow inshore zone, and a shift with increased size to pelagic organisms in neritic waters. This transition from inshore areas to a more pelagic existence appeared to be size dependent occurring between 50-60 millimeters. Other investigators have also noted a shift to pelagic waters although Allen (1974), working with a chum population in British Columbia, concluded that the transition occurred at 78 mm. Harris and Hartt (1977) found large chum (70 mm) in the nearshore waters of Alaska through July and August. Also described in the Hood Canal studies were temporal shifts in the diet of chum. Early in the migration period, Simenstad and Kinney (1978) noted selection for crustacean larvae, juvenile shrimp and calanoid copepods and hyperiid amphipods. Another conclusion reached by both Simenstad and Kinney (1978) and Bax et. al. (1978) was size selective predation on harpacticoid copepods, particularly in the neritic zone. Simenstad and Kinney (1978) state, "...some indication, though far from conclusive, that intense size-specific predation was depressing the mean size distribution of epibenthic harpacticoids during the peak out-migration period, suggesting overexploitation of the prey source."

Miller et. al. (1977) examined the abundance, distribution, and food habits of nearshore fishes in northern Puget Sound. They determined that epibenthic crustaceans were predominant in the food webs of the majority of nearshore fishes they examined, including salmonids which occupied this zone during various times of the year.

A particularly interesting finding has been the minimal amount of predation on juvenile chum by coho smolts. Other investigators (Parker, 1971; Walker, 1974) have implied high predation rates on juvenile chum and pink by coho smolts. However, the Hood Canal (Schreiner et. al., 1977; Bax et. al., 1978; Simenstad and Kinney, 1978) and Nisqually Reach studies (Fresh et. al., 1978) found little evidence of intense predation by coho smolts. Predation by resident immature chinook was not investigated in any of these studies. The abundance of Puget Sound resident chinook has increased considerably in recent years as a result of the WDF sport fishery enhancement program. The predatory habits of these fish are being investigated by WDF in an on-going study.

Despite the large amount of evidence for epibenthic feeding by juvenile salmon, the studies of Bailey et. al. (1975) in Traitor's Cove, Alaska, point toward pelagic organisms as the predominant prey item of pink and chum in that area. Bailey et. al. (1975) examined the food habits of juvenile pink and chum less than 60 mm and found epibenthic organisms to be rare in the stomach contents. However, the authors point out that the topography of Traitor's Cove is that of steep rocky shorelines which do not allow benthic feeding. These fish appeared to be selectively consuming pelagic organisms such as cladocerans, decapod zoeae and larvaceans. Pink and chum fry in Traitor's Cove were not consuming large numbers of barnacle nauplii which constituted 4 to 94% of the available plankters but only 14 and 3% of the prey eaten by pink and chum, respectively. Another interesting finding of this study was the increased feeding rate at low water velocities. Maximum feeding occurred between 0-10.7 centimeters per second (cm/s); feeding ceased at 19.9-24.4 cm/s.

Allen's (1974) work in British Columbia also indicates heavy utilization of pelagic forms. He found that during the first 4-6 weeks in saltwater, juvenile pink and chum from the Big Quilicum River moved along in the intertidal zone at depths of 1½ to 5 meters. Preferred areas had low current velocities and cover present (often in the form of sargassum beds and wharves). His analysis of the stomach contents of Big Quilicum pink and chum fry revealed the six most common prey items to be pelagic zooplankton. However, the size of fish sampled and capture locations are not indicated.

Mason's (1974) studies of juvenile chum feeding in a small British Columbia estuary are particularly interesting. His work revealed that small chum fry were feeding on freshwater, estuarine and marine food chains as they apparently moved with the tides between the upper and lower intertidal zone at the mouth of a small creek. The salinity changes involved in these movements were 0-27 parts per thousand. Fry captured in the lower portions of the intertidal zone contained primarily copepods, amphipods and insects in that order. Those captured in the upper intertidal zone contained amphipods, copepods, and insects. Residency time for chums in this estuary ranged up to 30 days and averaged 1-2 weeks. It was also noted that coho fry occupied the upper intertidal zone at low tide where they were actively feeding, but moved upstream at high tide, presumably to avoid saline water.

Growth rate in the estuary and inshore areas is very rapid and could be a critical parameter. Healey (1979) estimated the rate of increase in weight to be 6% per day for chums in the Nanaimo estuary. Parker (1971), Johnson (1974) and Walker (1974) have suggested a high mortality rate during the early marine phase attributable to coho predation. Parker (1971) concluded that because of their rapid growth rate, pink and chum soon become too large for coho predation, suggesting the importance of an abundant food supply to juvenile salmonids (probably includes chinook) during the inshore period so as to assure rapid growth and escape from heavy predation.

Estuarine and Shoreline Alteration

Most Puget Sound and Washington coastal estuaries have been altered considerably as a result of dredge and fill projects, jetties, bulkheads, marinas and pollution. The major metropolitan areas of western Washington are located at river mouths and their development has had tremendous impact on the physical features of these former estuaries. The U.S. Geological Survey has prepared a report documenting major changes in eleven western Washington deltas (Bortelson et. al., in press). This report dramatically illustrates the loss of marsh and intertidal lands surrounding some of Puget Sound's major deltas. Of the approximately 91 square kilometers of marsh land determined to be present in the eleven deltas in the early 1800's, 55 square kilometers or 60% has been lost. In addition, there was an undetermined amount of marsh lost prior to the first mapping of these areas. The report also indicates a large amount of intertidal land lost; unfortunately early mapping of these areas is less precise and no overall figures are presented.

Studies which have actually been directed at assessment of the impacts of estuarine alteration or shoreline development on salmonids or their prey resource are limited; references are made by a number of authors to the possible impacts resulting from these alterations. In his studies of the Fraser River estuary, Dunford (1975) states that "the diverse marsh areas in the Duck-Barber-Woodward Island complex and Ladner Marsh provide suitable habitat for the production of many terristrial and aquatic invertebrates. These invertebrates in turn supply a vital food resource for many estuarine fishes, including the migrating juvenile salmon. Any further degradation of this habitat, by development or pollution, would further reduce the Fraser River salmon stocks." Royal (1973) cites data which indicates that coho smolts which do not pass through the upper polluted portion of the Grays Harbor estuary, have survival rates as much as 250% higher than smolts which must pass through this area. He also indicates that the same is true for steelhead smolts where the difference was even more dramatic at 600%. Niaman and Sibert (1978), in their examination of estuarine productivity, indicate that nutrients from various sources are trapped by physical structures such as woody debris, eelgrass beds, macroalgae, oyster beds and cobble bottoms. Modifications to the physical features of the estuary may reduce its ability to trap nutrients and therefore its productivity.

In an examination of the Squamish River estuary, Levy and Levings (1978) found that beach seine catches and seasonal patterns of abundance of chum fry were similar to those of Goodman and Vroom (1972), who collected their data prior to the construction of several dikes in the study area. On the other hand, the same authors postulate that their low chinook catches are attributable to industrial disruption. They point to the construction of training walls and dredged channels as having increased the flow of the river through the estuary which may consequently be sweeping fry into deeper water areas.

Reimers (1971) points out another aspect of watershed alteration and the role played by the estuary. He found that fall chinook in the Sixes River, Oregon remained in the mainstem river until early summer when water temperatures began to rise. At this point the majority of the population began migrating downstream into the estuary, where additional rearing occurs. Reimers (1971) suggests that logging throughout the watershed has caused reduced flows and increased water temperatures making the mainstem river less suitable for summer rearing while not significantly impacting the estuary. However, Naiman and Sibert (1979) have suggested that siltation due to extensive logging in the Nanaimo drainage has greatly reduced the size of eelgrass beds at the mouth of that river.

Pomeroy and Stockner (1976) have documented changes in the type and distribution of algae in the Squamish estuary in British Columbia as a result of dredging, land fill and diking. Although they do not relate any impacts of salmonids, they do show a change from estuarine to marine forms of algae in significant portions of the study area indicating a decrease in the actual size of the estuary.

Heiser and Finn (1970) observed large numbers of pink and chum fry inside marinas and warned that they may become trapped there eventually suffering from predation, an inadequate food supply and poor water quality. They also observed that small pink and chum (35-40 mm) were reluctant to move offshore into deep water around marinas or bulkheads.

Cardwell et. al. (1978) conducted studies in Birch Bay Village Marina in northern Puget Sound to investigate the problems of juvenile salmon entrapment, predation, water quality impacts and food avialability.

They concluded that chinook and chum entered the marina, but densities were no higher than in surrounding waters. A marking experiment indicated that chum were not necessarily trapped or delayed in the marina, and yet, small numbers of marked chum released inside the marina were recovered there 33-days after-release. The marked fish which remained in the marina appeared to grow at a rate comparable to those sampled outside the marina. They also found little predation of juvenile salmon by resident fishes in the marina.

Kikuchi (1974), in his review of the Japanese literature on eelgrass beds, documented the loss of fisheries for shrimp, crab, and several species of non-anadromous fish in the Seto Inland Sea following the disappearance of extensive eelgrass beds as a result of land fill activities, water pollution and increased turbidity.

Gerke and Kaczynski (1972) refer to the epibenthic organisms which they found to be so important to Puget Sound pink and chum, when they state, "The ecological zone that the epibenthic organisms inhabit is of primary concern when considering the present rate of altering the shoreline areas and beaches via land development. Piers, jetties, land fills, marinas, bulkheads, and other facilities that either disturb or destroy beach area could be highly detrimental to aquatic life, especially the kind that lives in association with the bottom substrate. Not only do these saltwater installations remove living area for economically important fishes, but they also eliminate habitat that supports the food these fish feed upon. This fact could very well have a great impact on the magnitude of future Puget Sound pink and chum stocks." Healey (1979) also refers to the epibenthic food resource when he points out, "In the Nanaimo and probably in other estuaries continued production of salmon depends upon the conservation of specific food resources and the habitat characteristics that make these resources available to the salmon...".

Smith (1977) examined the impact of log rafting on the intertidal benthos of the Snohomish River estuary in northern Puget Sound. Species studied included several epibenthic invertebrates important in salmon diets. His studies indicated that intertidal log rafting resulted in significant reductions in all the common species except Anisogammarus confervicolus, a free swimming amphipod. Smith (1977) also found that recolonization by epibenthic invertebrates occurred one to two months after the logs were removed.

Smith et. al. (1976) investigated dredging related impacts on various species of fish in Grays Harbor. The already badly polluted waters in Grays Harbor complicated the problem of isolating dredging impacts. Although they did not record any major fish mortalities or population shifts attributable to the dredging operation, Smith et. al. (1976a) did identify several subtle, long-term impacts such as increased turbidity, resuspension of pesticides and heavy metals, and disruption of benthic populations which serve as important food items. Smith et. al. (1976b) also examined the impacts of dredging and dredge spoil dumping on several important epibenthic invertebrates, including *Corophium* sp. They determined that the dredging operation resulted in smothering of benthic organisms, alteration of sediment characteristics, and changes in bottom elevation. The changes in sediment characteristics and increased elevation prevented *Corophium* sp. from recolonizing the area.

Iwamoto and Salo (in press) provide an extensive review of the literature on water quality requirements for chum, chinook and coho in the estuary.

Discussion and Recommendations

Recent studies in several areas along the Pacific Coast have begun to present a better picture of salmonid utilization of estuarine and nearshore areas. The studies of Reimers (1971), Lipovsky (1977), Sibert et. al. (1977), Dunford (1975), Healey (1979) and Mason (1974) have clearly shown that during their downstream migration to the sea, juvenile salmon, particularly chinook and chum, reside in the estuary and associated tide flats, sloughs and salt marsh, feeding upon epibenthic invertebrates and aquatic insects. The amount of time spent there is variable and may depend upon a number of factors including food availability, degree of alteration, and temperature fluctuations. Commonly identified prey items vary between locations and season but include aquatic and terrestrial insects, *Corophium* and *Anisogammarus* amphipods, mysids, and harpacticoid copepods. Chinook utilization of these areas could be quite significant, particularly the length of residency which often extends into late summer. The degree of utilization of the estuarine salt marsh, tidal flats, creeks and sloughs by pink, coho, and sockeye appears to be less significant although Mason (1974) and Merrill and Koski (1978) have shown some use of the upper estuary by coho fry. Limited sampling by the Olympia Fisheries Assistance Office in the tidal sloughs of the Nisqually Delta in southern Puget Sound revealed some coho feeding upon gammarid amphipods, mysids, and aquatic insects. There is very little data regarding the utilization of these areas by steelhead. Additional investigations are needed to determine the importance of the salt marsh, tidal creeks and sloughs as an early foraging area for pink, coho and steelhead.

One other fairly clear indication from work in Alaska, British Columbia, Oregon and California is the variation exhibited not only between areas, but also between estuaries within areas, and possibly between years. Sibert and Kask (1977) examined the diets of chinook and coho in four different British Columbia estuaries and found statistically significant differences in prey items between the four areas and between species. Findings in Alaska, British Columbia, Oregon and California estuaries may not be applicable to Puget Sound. Congleton's (1978) work in the Skagit delta is providing important information for that system; however, considerable variability in environmental conditions and fish assemblages exists within Puget Sound and several other areas should be examined.

Likewise, the work of Gerke and Kaczynski (1972), Miller et. al. (1977), Fresh et. al. (1978), Schreiner et. al. (1977), Simenstad and Kinney (1978) and Bax et. al. (1978) have given new insight into the movement and diet of juvenile salmonids during their migration along shallow shoreline areas of Puget Sound. Primary emphasis in most of these studies was placed on chum salmon. It is quite evident that in an unaltered situation, chum migrate through the shallow inshore zone, feeding on epibenthic organisms during their initial marine residency. Some observers have noted a preference by pink and chum fry for areas of low current velocity and eelgrass beds, or other areas of vegetation cover. Here they apparently find refuge from predators and an abundance of prey organisms of the proper size (harpacticoid copepods, gammarid amphipods, and cumaceans). There appears to be transition to deeper waters and pelagic forms of plankton at a size of approximately 55 mm. Growth during the inshore period is rapid and may be crucial in avoidance of predation and capture of an adequate food ration. Although the inshore food habits and movements of juvenile chinook, coho, and pink have not been as thoroughly examined, these fish also enter into benthic food chains (Fresh et. al., 1978; Gerke and Kaczynski, 1972). Additional investigations are needed to determine preferred food items and migration routes of these species plus steelhead during their inshore residency in Puget Sound.

The available literature is quite positive regarding the utilization of salt marshes, tidal sloughs, tide flats, and shallow shorelines as initial nursery grounds for juvenile salmonids. However, few investigators have examined the importance or contribution to overall survival of early feeding in any of these areas. It has generally been accepted that mortality of juvenile salmonids during early sea life is related to body size at the time of entrance into marine waters. Therefore, extensive feeding and rapid growth in estuarine and shallow inshore areas could be decisive in total marine survival. Reimers' (1971) data illustrates a definite survival advantage gained by fall chinook from extended residency in an Oregon coastal estuary. While Reimers' (1971) conclusions may not be applicable to the numerous small estuaries located at the mouths of Puget Sound rivers, his findings may relate to the total Puget Sound ecosystem, including its salt marshes, tidal sloughs, tide flats, shallow inshore and deeper pelagic zones. Additional studies are needed of the role played by the various components of the Puget Sound ecosystem in determining total survival and adult run size.

Wissmar and Simenstad (1979) have proposed additional studies of Hood Canal chum salmon which will attempt to relate returning adult run size to conditions in the nearshore environment at the time of entrance as juveniles. They have hypothesized that total marine survival is determined by the availability of epibenthic and pelagic food resources during the juvenile out-migration period through Hood Canal. The investigators hope the findings of this study can be used in planning future releases of hatchery chums to coincide with high abundance of preferred food resources, thereby maximizing survival and decreasing competition with wild chum stocks. These studies could add significantly to our knowledge of the importance of shallow shoreline areas as well as providing important tools for increasing salmon stocks. This work will not however, examine environmental conditions or food availability in the salt marsh or tidal flats adjacent to the river mouth during the out-migration period.

There is very little data on the behavior, distribution, and diet of hatchery released fish upon entering the estuary and inshore environment. Based upon the Fishery Research Institute's work in Hood Canal, Wissmar and Simenstad (1979) have assumed that hatchery chum released at a size of 55 mm or approximately 400/lb. will move directly into deep water and begin feeding on pelagic zooplankton without extensive utilization of the shallow inshore zone, thus avoiding competition with wild chum stocks during their inshore period. However, it was not possible to distinguish between hatchery and wild fish in the Hood Canal studies. Congleton's (1978) work is being conducted in the Skagit marsh where very few hatchery released chum or chinook would be encountered. Reimers (1971) discusses the implications of hatchery releases into the Sixes River of fall chinook which reside for extended periods in the estuary. He warns that they would most likely only result in greater competition in the estuary with co-existing wild fish and little increase in total run size. He further recommends that enhancement of fall chinook in the Sixes River be directed toward fish which rear in the mainstem or tributaries until entrance into the ocean. Primary emphasis of future salmon enhancement in Puget Sound has been placed upon chum salmon because of the ease with which they are propagated and their low interception rate. Therefore, the early movements and feeding habits of artificially produced chum and the ability of the estuary and nearshore environment to support increased numbers of these fish needs to be investigated.

An important component of the future magnitude of Puget Sound salmon stocks plus options for their enhancement, may well depend upon knowledge and preservation of epibenthic prey organisms in estuarine and inshore areas. The habitat requirements of these animals, particularly the harpacticoid copepods, are poorly understood or not readily available and need to be recognized by resource managers. Some literature pertaining to these organisms is available for other areas, but there is very little data pertaining to Puget Sound. There is also a need for an increased understanding of the impacts of various habitat disturbances on both juvenile salmonids and epibenthic organisms. The earlier cited studies provide some understanding of this problem, but still leave many questions. Do changes in flow patterns resulting from marinas, piers, jetties, and dikes alter substrate composition and impact surrounding epibenthic communities? What are the impacts on epibenthic invertebrates of reduced freshwater inflow and increased salinity in the estuary? Little is known of the behavior of juvenile salmonids which enter the marine environment through a highly altered estuary and must travel some distance before encountering naturally occurring shallow littoral feeding areas, i.e. Commencement Bay or Elliot Bay. Do salmonids denied these natural habitats move directly into deep water areas and begin feeding on pelagic zooplankton? If they do, is there an overall decrease in growth and survival resulting from a higher expenditure of energy pursuing the proper size prey and evading predators? A cursory examination of present Puget Sound chum stocks versus the degree of degradation of the estuary and shorelines associated with their river of origin, presents some interesting trends which might lead an observer to speculate that chum salmon are highly dependent on estuarine and shallow shoreline areas. These and other questions need to be answered before wise decisions can be made regarding the location and amount of estuarine and shoreline developement that would be permissible relative to salmonid habitat requirements for survival.

Major Information Needs

1. Utilization of the salt marsh, tidal sloughs, and tide flats by pink, coho, sockeye and steelhead has not been conclusively addressed. A thorough examination is needed of the amount of feeding and length of residency of these species in the upper estuary.
2. Because of the high degree of variability in food habits and habitat utilization exhibited in other areas, and the diversity of habitat and biological communities existing within Puget Sound, there is a need to examine several salt marshes and associated deltas within Puget Sound.

3. The inshore migration and food habits of juvenile chum in Hood Canal have been studied quite extensively by the Fisheries Research Institute. However, similar investigations are needed for chinook, coho, pink, sockeye, and steelhead in both Hood Canal and other areas of Puget Sound.

4. Studies are needed to determine the relationship between total survival and early feeding and growth in estuarine and inshore areas. Studies of this type may also require a knowledge of production and survival during the freshwater period and its affect on the number of out-migrants entering estuarine and nearshore areas. Considerable information could be gained by simultaneously monitoring environmental conditions in freshwater, estuarine, and nearshore environments during salmonid out-migration.

5. The recent emphasis on artificial production has greatly increased the number of juvenile salmonids entering estuarine and nearshore areas. There has been much speculation, but little work directed toward determining the ability of these areas to support additional out-migrants. Before these questions can be addressed, work is needed to determine the distribution and food habits of artificially propagated salmonids.

6. Additional information is needed regarding the distribution and life history of many of the estuarine and inshore epibenthic invertebrates (particularly the harpacticoid copepods and estuarine aquatic insects) which serve as an important prey resource for juvenile salmonids. Additional information is also required to predict the response of these organisms to environmental disturbances. It was not within the scope of this paper to review all the existing literature on this subject although the need certainly does exist because of its importance to the salmonid resource.

7. Because of the questions regarding the ability of salmonids to adapt to altered conditions and the existence of relatively strong natural runs of some species of salmon in highly altered areas (fall chinook in the Green River must migrate through Elliott Bay), information should be gathered on the distribution and food habits of salmonids in highly altered estuarine and shoreline situations.

8. Additional studies of Puget Sound salt marsh productivity and their contribution to the salmonid resource are needed. Possible relationships between marshes, epibenthic invertebrates, and pelagic productivity need to be explored. In addition, possible links between eelgrass beds, epibenthic invertebrates and pelagic organisms should be investigated.

9. There is an overall lack of information regarding steelhead once they have left the freshwater environment. No reliable data was located which identified the distribution, residency, or food habits of these fish during estuarine, nearshore, pelagic or oceanic residency.

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