Estuarine science and management needed to maintain Pacific salmon production

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Abstract

This paper provides a brief review of the scientific data and management strategies used for maintaining Pacific salmon habitat in north-east Pacific estuaries. Estuaries within metropolises (e.g. Vancouver, Seattle, San Francisco) in the area support major commercially significant stocks of salmon. Comprehensive plans involving ecological zoning and guidelines for habitat management and restoration are in place in the urbanized estuaries, but inference is heavily relied on instead of specific data. Managers are using semi-quantitative rating guides to try and achieve 'no net loss of productive capacity' for salmon production. Long-term data sets on estuarine ecosystems are necessary to determine specific habitat factors which affect salmon production, but often scientific sampling programs cannot be maintained at the time scales needed. Integration of scientific research with monitoring and evaluation schemes may be the only way the required data can be obtained. Monitoring should be designed to answer specific hypotheses.

Keywords: north-east Pacific, salmon, habitat management, monitoring.

Introduction

There has been an inexorable movement of people and industrial development towards the shores of the north-east Pacific since the arrival of Europeans in North America. Human settlements have disrupted many of the estuaries in our area, except in relatively undeveloped areas such as Alaska. In Puget Sound, for example, the area of sub-aerial wetlands on 11 major estuaries has been reduced by 58% since the 1880s (Thom & Hallum 1991). Commercially harvestable salmon stocks have persisted in the populated areas. Fisheries for salmon within urbanized estuaries are intensive in some areas of the north-east Pacific. In the Fraser River Estuary, which is totally within the Greater Vancouver Regional District (population 1.2 million people), annual catches of sockeye salmon (*Oncorhynchus nerka*) using gill-nets have ranged between about 0.3 and 3 million fish in the past 10 years (Anon. 1990). The challenge for estuarine scientists and habitat managers in our area is to continue the production of salmon from such estuaries, and increase production to historical levels, where possible.

In this paper I review the data showing how key habitats in north-east Pacific estuaries enable salmon survival, and how man's activities can modify these functions. I then describe the current strategies and policies used for habitat management and protection. Suggestions are provided about how monitoring and habitat management might be integrated with scientific research to improve our knowledge base.

Estuary functions for salmon survival

Estuaries in the north-east Pacific provide habitat for three of the major life history functions of salmon, namely migration, rearing, and spawning. As all of the salmon (chum salmon (*Oncorhynchus keta*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), pink salmon (*O. gorbuscha*), and chinook salmon (*O. tshawytscha*), and steelhead (*O. mykiss*)) using north-east Pacific estuaries are anadromous, successful migration through the estuaries as adults and juveniles is vital. Salmonids grow and acclimate from fresh water to salt water in Pacific estuaries for varying time periods, depending on physiological requirements and life history attributes (Scott & Crossman 1973, Groot & Margolis 1991). The rearing period of juvenile salmon in estuaries ranges from a few hours for pink salmon to several months for chinook salmon. Certain stocks of pink and chum salmon spawn in brackish water near estuaries, but in most instances salmon use freshwater spawning habitat.

Migratory habitats

Water quantity and quality changes, together with climatic effects such as changes in precipitation and river discharge patterns, can influence migration and survival of both adult and juvenile salmon. Movement and dispersal of salmon fry from rivers into estuarine rearing habitat is usually related to discharge (e.g. chum salmon fry into Fraser River Estuary, Figure 1). Passage through estuaries is particulary critical for adult salmon on their spawning migration. For example in 1990, at the

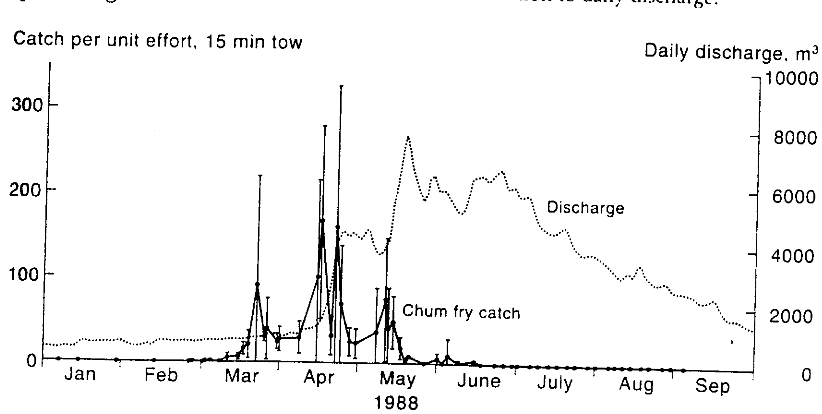

Figure 1.
Catches of chum salmon fry per 15 min trawl (mean, standard deviation) (own data) in the lower Fraser River at Port Mann, in relation to daily discharge.

Somass River Estuary in British Columbia, about 100 000 sockeye salmon died in the estuary or lower river because of the combined effects of low dissolved oxygen and high river temperatures. The low dissolved oxygen effects were attributed to biochemical oxygen demand from wood waste and pulp mill effluent from a mill located on the estuary (Waldichuk, 1993). In the Sacramento-San Joaquin system in California, survival of chinook salmon was directly related to the amount of water abstracted for irrigation which in turn was related to estuarine residency and dispersal of juvenile fish (Kjelson & Brandes 1989).

Rearing habitats

Rearing habitat in north-east Pacific estuaries has been lost primarily by industrial development and urbanization, as shallow intertidal areas have been filled to create ports, airports, and housing developments. In some instances river training walls, causeways, and dredging (Levings 1980) have affected nearshore processes which in turn can affect estuarine functions, especially primary production. River flow effects can also influence rearing habitats. The flushing frequency of small estuaries and lagoons used by rearing steelhead trout in California has been decreased recently because of reduced river flows due to irrigation practices. These lagoons were recognized earlier as important rearing habitat (Shapovalov & Taft 1954).

Major research programs to investigate the importance of north-east Pacific estuaries for rearing of juvenile salmonids were conducted in Washington and British Columbia in the 1970s. Results of these programs summarized by Simenstad *et al.* (1982) and Healey (1982) showed clearly that young salmon used food and habitat in estuaries. Work in the Nanaimo River Estuary, on Vancouver Island, and in Hood Canal, in Puget Sound, examined food webs leading to juvenile chum salmon. Chum salmon fry were supported by harpacticoid copepods using detritus arising from heterotrophic production (Sibert *et al.* 1977; Nanaimo River Estuary), as well as crustaceans that grazed directly on algae (Simenstad & Wissmar 1985; Hood Canal). There were multiple carbon sources identified, including material coming into the estuary from the river (riparian sources), from eelgrass (*Zostera marina*), from coastal marsh plants such as sedges (*Carex lyngbyei*), and from algal production on sand or mud flats (e.g. interstitial diatoms).

As well as providing detritus, vascular plants in north-east Pacific estuaries also provide structure that appears to determine the abundance of invertebrates (e.g. gammarid amphipods; Pomeroy & Levings 1980). The orientation of the plants also provides juvenile salmonids with opportunity for grazing. Webb (1991) documented the importance of the blade habitat of eelgrass for harpacticoid copepods. Juvenile chum salmon graze on the epiphytic copepods at high tide when the plants create vertical structure in the shallow water.

Experimental results also demonstrate the importance of estuarine rearing for salmon survival from juvenile to adult stages. Initially, research to determine if salmon benefited from residing in estuaries focused on analyses of adult scale patterns. Reimers (1973), working in the Sixes River Estuary in Oregon, found that a particular life history type of chinook salmon that used the estuary longest survived better relative to other life history types that moved through the estuary faster. Transfer experiments were used at the Campbell River Estuary in British Columbia to test the survival benefit hypothesis. In this work, marked populations of juvenile chinook salmon were released in three years into four habitats: river, estuary, transition, and marine. Results from recovery of marked fish from the fishery and from the spawning grounds indicate that salmon that experienced the estuary survived best (Levings *et al.* 1989). This result held even after corrections for effects due to a small size difference in the fish released in the three years (C.D. McAllister, pers. comm.). Mechanisms leading to the differences in survival for the chinook salmon released to the four habitats are not clear. More predators were present in marine habitats. In addition, the chinook salmon released directly to the sea were not exposed to brackish water conditions, which were probably necessary for the fry to adapt from fresh to salt water.

Management of salmon habitat in estuaries

Management of water quantity and quality

Because salmon migrations through estuaries are related to river discharges, estuary management schemes must consider river basin activities such as water diversion projects. For normal ecosystem functions, an adequate level of river discharge is needed to maintain a large ratio of river flow to tidal flow in highly stratified, salt wedge estuaries. Relationships between flow and survival of chinook salmon in the Sacramento-San Joaquin Delta are used to help manage water diversions in the rivers (Kjelson & Brandes 1989). Since flushing of estuaries can also influence water quality, water flow is also important in water quality considerations. The maintenance of adequate dissolved oxygen levels, for example, is critical for juvenile salmonids migrating or rearing through estuaries (Birtwell & Kruzynski 1989).

Rating schemes for rearing habitat

Habitat managers have utilized scientific information obtained from ecosystem and food web studies and have developed a variety of management schemes. These have included the development of semi-quantitative rating tables (e.g. Hamilton 1984, Simenstad *et al.* 1989), estuary management plans (e.g. Anon. 1991), and zoning of estuarine habitat (Williams & Colquhoun 1987). Data on areal extent of specific types of vegetation (sedge, eelgrass), slope of the intertidal zone, substrate, and salinity type are commonly used to rate habitat for its importance to juvenile salmon. Areas that are characterized by large areas of vegetation, shallow slopes, and fine substrates are afforded the most protection. Sand flats, mud flats, and riparian areas are given lower ratings. Results from survival experiments such as those conducted at the Campbell River Estuary (Levings *et al.* 1989) support management decisions to protect estuarine rearing habitat. However the Campbell River work evaluated the importance of the entire estuary, which included marsh, sand flat, and

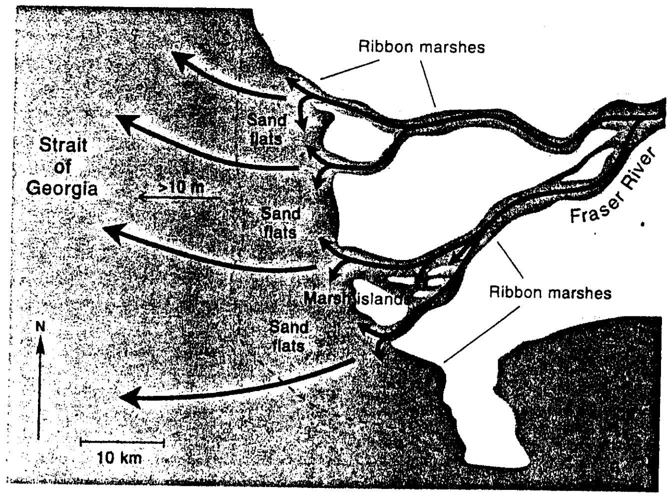

Figure 2.
Inferred migration and rearing routes of juvenile chinook salmon through the Fraser River Estuary, showing major marsh and sand flat habitats (redrawn from Dorcey *et al.* 1978).

mud flat habitats. The survival benefit of the individual habitats still need to be assessed, but this is an almost intractable problem with present technology and ecological knowledge. For our estuaries, an evaluation of the importance of mud flat and sand flat for salmon survival in comparison to marsh habitats is needed. Extensive sand flats (14 000 ha) are found seaward of marshes at the Fraser Estuary, for example (Figure 2), and there is some evidence that chinook salmon growth is at least as fast on the sand flats compared to the marshes (Figure 3). It is likely that the fish move between the habitats, perhaps on each tidal cycle, so an evaluation of the two areas for salmon survival is a very difficult problem to research.

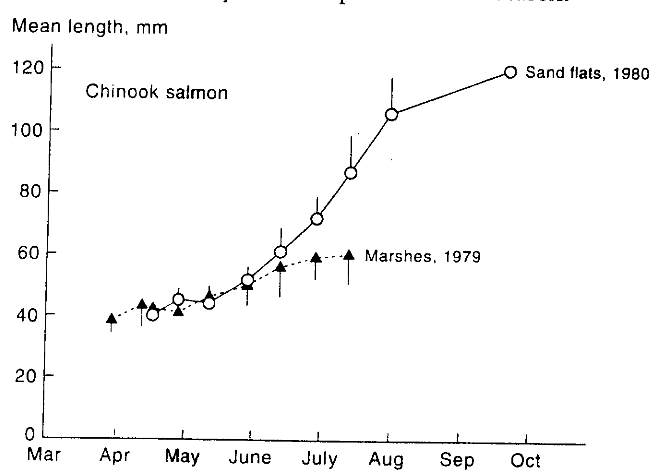

Figure 3.
Growth in mean length (with standard deviation) of juvenile chinook salmon at marsh and sand flat habitats in the Fraser River Estuary (circles: own data from sand flats (1980) (Steveston Pit; see Gordon & Levings 1984); triangles: Levy & Northcote's data (1982) from marshes, obtained in 1979).

Habitat compensation and restoration

In some instances, efforts have been made to replace marsh habitat destroyed by industrial development, to satisfy government agencies' 'no net loss' policies (Anon. 1991; Rylko & Storm 1991, Kentula *et al.* 1992). Kentula *et al* (1992) have shown approximate net losses of vegetated habitat of 43% in Oregon and 26% in Washington, indicating that compensation or mitigation programs have not been successful in those jurisdictions. Replacement ratios, that is the ratio of the area of the restored or developed habitat to that of the lost area, have been developed to provide maximum protection for vegetated fish habitat. For example, to compensate for loss of sedge marshes and eelgrass in the Fraser River Estuary, a 2 : 1 ratio (compensatory area : lost area) based on areal measurements is usually required by fish habitat managers (Anon. 1991). A 1 : 1 ratio is only needed for unvegetated habitats. However sufficient data to develop a balance sheet on gains and losses of habitat types in the estuary are not available. Monitoring programs to assess the success or failure of habitat compensation are usually of short duration and regulatory agencies have been unable to evaluate compensation projects because of this (Kentula *et al.* 1992).

Improving the integration of science and management

One of the possible strategies to increase the data bases on salmon ecology in northeast Pacific estuaries could involve more integrated research and management programs. Long-term data sets, which often accrue via monitoring programs, are necessary to sort out effects of natural variation from man-induced changes. Some changes, for example river flow variations and marsh development, occur at the decade scale (Levings 1980) which is usually much longer than the life span of most research projects. Management and research programs which integrate activities in the drainage basin with those in the estuary are clearly needed (e.g. Dorcey 1991). In small estuaries, long-term monitoring programs could be established to test hypotheses concerning the significance of movement between habitat types for juvenile salmon. In large estuaries, selected 'audit reaches' could be chosen for detailed monitoring, using sampling schemes that would satisfy both habitat managers and scientists. An outline of a proposed program is shown in Figure 4. Some of the vital information that could be collected in tests of specific hypotheses include salmon residency, growth, and survival in major habitats, productivity at several trophic levels, and gain/loss of vegetated and unvegetated habitat. Techniques to explore food webs such as stable isotope investigations (e.g. Simenstad & Wissmar 1985)

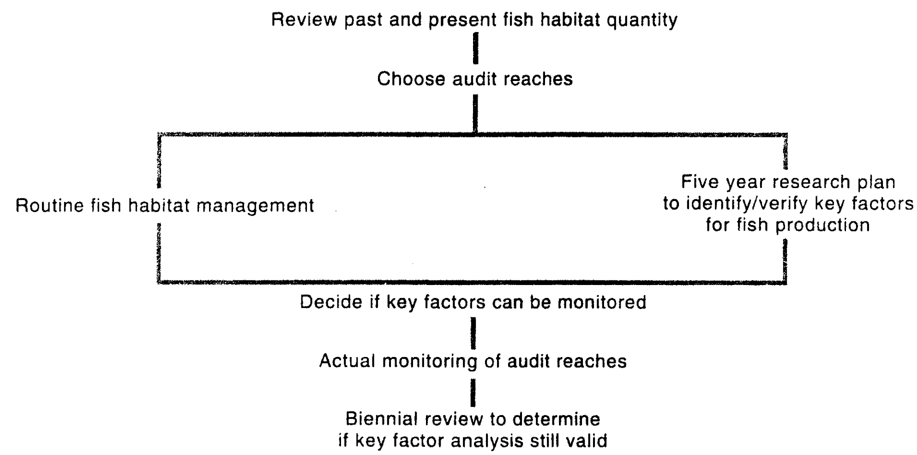

Figure 4.
A possible effective scheme to use monitoring data from estuarine habitat management for verifying and furthering scientific knowledge.

could also be tested in the program. Data from the audit reach would be reviewed every five years by both groups to see if the sampling scheme is still valid for management and research. If managers and scientists can compromise and agree on joint sampling as a way of improving data bases for habitat management, knowledge would be continually updated in a timely and efficient manner. This strategy could maintain or improve conditions in some of the key habitats for Pacific salmon survival.

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