# Two Decades of Fish Habitat Restoration and Bioengineering on the Fraser River Estuary, British Columbia, Canada

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## I. INTRODUCTION

The Fraser River estuary is the most important estuary on Canada's Pacific coast. Most of the Province of British Columbia's populations live at the river mouth, and the estuary is an international shipping port that supports over 50 species of fish, including the largest salmon populations of any single river in the world [1]. To achieve a net gain of fish habitat, a goal of Canada's fisheries management policy, a large number of habitat restoration projects have been conducted in the estuary since 1980. In this paper I review some of the successes, failures, and lessons learned over the past twenty years. References [2] and [3] provide ecological assessments of some of the projects on the inner estuary, and reference [4] provides additional summary information.

In this paper I focus on bioengineering aspects of some of the older projects and an ecological assessment of more recent projects conducted on the outer estuary (Sturgeon and Roberts Banks).

## II. METHODS USED TO CONSTRUCT HABITAT

Most of the projects have involved transplanting single species of vegetation, including sedges (*Carex lyngbyei*; *Scirpus americanus*), pickleweed (*Salicornia virginica*), eelgrass (*Zostera marina*), and riparian shrubs such as red osier dogwood *(Cornus sericea (stolonifera)*. Several of the larger projects to restore brackish marsh have used placement of dredged sand as a medium to increase the substrate elevation. This was done so the vegetation could be planted at the intertidal zone level that matched its adaptation to specific durations of emergence and submergence. In some instances, very large volumes of sand have been used. For example 40000 $m^3$ of sand from a suction dredge were placed on an intertidal area of Sturgeon Bank, adjacent to the lower river shipping channel ("Steveston Bend"), in March 1980 [5]. The purpose was to develop a sand island (hereafter "Outer Sand Island") to be planted with vegetation. Because of technical problems with the dredging, less sand was deposited than originally intended. In 1987 and 1988 additional dredged material was added and the final volume deposited was ~100000 $m^3$. Front end loaders or bulldozers were used in several small projects during low tide to grade substrates to particular elevations.

Botanical methods employed for the transplants included the movement of shoots, sprigs, and cores from nearby donor sites of natural marshes. Detailed descriptions of most of these methods are available in [6].

Development of marshes on dredge spoil islands can occur without human intervention since several islands in the lower river [e.g. Steveston Island (also known as Shady Island) and Albion Island] are well vegetated without being subject to transplantation [7, 8]. I refer to some comparative data from these artificial islands when possible, although vegetation data on most of these naturally colonized islands are generally not available.

## III. METHODS USED TO ASSESS THE PROJECTS

Numerous authors have recognized the importance in the evaluation of coastal habitat restoration from the ecological [9,10,11] and socio-economic perspective [12]. In spite of this recognition, there has been limited followup on the > 50 individual projects conducted in the Fraser River estuary. Below I describe some of the methods and approaches that have been used in the evaluations that have been completed and published.

## IV. GEOPHYSICAL METHODS

The stability of the sand used to develop the areas for planting was a key factor in the evaluations of coastal habitat restoration. Sand eroded quickly on Outer Sand Island because of wave energy. The sand was moved shoreward by wave action, with waves up to 1.0 m in height observed, and the peak of the island eroded by ~1 m by May 1980 [5]. In later years surplus concrete pipe was placed on the seaward site of Outer Sand Island to reduce erosion. By 1997, the island's shape and size had been modified significantly and a lagoon had formed on the landward side. Currently, the island is ~2 ha in size and is mostly submerged at high tide.

Similar problems were encountered with small projects in the lower Fraser River, where wave action from passing vessels caused erosion. Floating logs were successful in dampening the waves, but long term maintenance was required to secure them.

In 1993, mud and sand placed in an intertidal basin on Roberts Bank was protected by riprap revetments on the seaward side and a causeway to a ferry terminal land on two other sides. This sediment has been relatively stable and has enabled the development of a 4 ha salt marsh.

A hydrological model has been developed that enables the prediction of submergence: emergence ratios along the intertidal gradient [13]. The model, which considers tides, river flow, and currents as well as geodetic elevation, was used to evaluate whether marsh plants had been transplanted to the correct intertidal elevation within the inner estuary[2]. It is not known whether the model has been used for planning restoration in the estuary. Reference [14] used a physical model to help select habitat development sites in the estuary and also listed biological and engineering criteria for site selection.

## V. BIOGEOCHEMICAL

The only biogeochemical parameters evaluated at transplant sites were surficial sediment grain size, chlorophyll a, and organic content of sediment. During a one year monitoring period at an early transplant site on Steveston Island [15], organic material (loss on ignition) was lower (0.45%) inside the planted block relative to outside the block and donor sites (0.64% outside, 0.77% at *S. americanus* donor sites, 5.85% at *C.lyngbyei* donor sites). Chlorophyll a levels inside the planted block were higher (2.00 $\mu g \cdot cc^{-1}$) than those in adjacent habitats (1.28 $\mu g \cdot cc^{-1}$) and were comparable to *S. americanus* donor sites (1.10 ($\mu g \cdot cc^{-1}$) but much lower than *Carex lyngbyei* donor sites (23.29 ($\mu g \cdot cc^{-1}$). These data indicate that the transplanted habitats apparently fostered the growth of sediment algae, which was reflected in the increased chlorophyll a levels. However, vegetation development, and hence detrital input, was not sufficient to result in an increase in the organic content of the sediment.

## VI. BIOLOGICAL

### A. Vegetation survival

In the early years of the transplant projects, erosion of planted plugs and sprigs was a problem [15]. In more recent projects, stabilization of the sediments, and hence better retention of the planted material, has been improved as biologists and engineers gained experience with the technology. Reference [4] provides a useful chronology of the transplant success for 42 marsh transplants (1979-1997).

### B Vegetation productivity, growth and diversity

Productivity (as estimated by annual above ground peak biomass) of transplanted *C.lyngbyei* in the inner estuary was comparable to reference marshes within two to five years [2]. Physical conditions (e.g. stability, submergence: emergence ratios) were as important as temporal aspects. Rhizomes from transplanted *C. lyngbyei* extended at a rate of about 5 cm • $month^{-1}$ [15]. To my knowledge, there are no other growth estimates for transplanted marsh species available from the Fraser River estuary.

### C. Vegetation species composition and biodiversity

At several sites the final species composition in the transplanted marshes was different than expected. For example, Outer Sand Island was initially transplanted with the brackish marsh species *C. lyngbyei* and *S. americanus* in 1980 (total of 2084 plugs) [5] and again in 1987 and 1988, ["several hundred plugs" of the latter two species in addition to a third species (*S. maritimus*) [16]. Surveys in 1997 showed that nine or 10 y after the transplants, 20 additional species were present, but one of the target species (*Carex lyngbyei*) was not recorded. The vegetation communities were dominated by the dune grass (*Elymus mollis*) with several dense patches of a different sedge species (*C. macrocephala*). In general, the plant community was characteristic of a coastal sand dune. Other species present were glasswort (*Salicornia virginica*), seashore saltgrass (*Distichlis spicata*), and sea plantain (*Plantago maritima*). These species obviously colonized the sand island through natural dispersal of seeds, rhizomes, or fragments from adjacent natural areas. However, the plants that successfully colonized the island were not the brackish sedge species that were initially planted. This was likely because salinity was higher at the Outer Sand Island – the target species are adapted to lower salinities and are found in natural habitats further up the estuary where freshwater is dominant.

Natural colonization of dredge spoil islands can eventually lead to a vegetation community similar to those in natural sites with matching salinity and elevation, although these aspects have not been thoroughly researched. In 1980, [8] surveyed Steveston Island, a dredge spoil island at least 20 y old. Thirty-one species of vascular species were found, and the vegetation was dominated by plants characteristic of natural estuarine ecosystems in the estuary such as *C. lyngbyei* and *S. validus*.

Data on the quality of detritus produced by decomposing vascular plant debris from transplanted vegetation relative to many non-target vegetation species are not available. For example, while the importance of detritus from *C. lyngbyei*) for energy flow in the ecosystem has been documented [17], detritus from *C. macrocephala* has not been studied.

### D. Habitat use by invertebrates and fish

Invertebrate and fish use of the habitats is a key index of the success of the restoration projects, but except for [2] there have been few investigations into this aspect at the Fraser River estuary.

In 1983, three years after the initial development of Outer Sand Island, [7] found that the abundance of important salmon food items such as harpacticoid copepods (< 10 $\cdot sample^{-1}$) and insect larvae (none obtained) was much reduced relative to reference locations and older, naturally vegetated dredge spoil islands such as Albion and Steveston Island (up to 468 harpacticoids$\cdot sample^{-1}$) and 8 insect larvae$\cdot sample^{-1}$). Seventeen years after initial development, harpacticoids were about as abundant on Outer Sand Island and reference locations, but only a few insect larvae were found at Outer Sand Island [18]. Differences in sampler type make a direct comparison of the data between 1980 and 1997 difficult.

In 1983, Outer Sand Island was used by relatively small numbers of chinook salmon (*O. tshawytscha*; hereafter chinook salmon). Mean peak catches of 20 chinook salmon$\cdot sample^{-1}$ at the sand island compared to ~ 200 chinook salmon$\cdot sample^{-1}$ at Albion Island (dredge spoil island) and Garry Point Slough (natural marsh) [7]. Using the same sample gear in 1997, [18] found low numbers of chinook salmon and juvenile chum salmon (*Oncorhynchus keta*; hereafter chum salmon (5$\cdot sample^{-1}$ and 0.5$\cdot$ $sample^{-1}$

respectively) at Outer Sand Island. However, reference site catches were lower for chinook salmon (1.5• $sample^{-1}$) and higher for chum salmon (1.0 • $sample^{-1}$)

E. Food web analysis

Stable isotope analysis is a contemporary method used to determine food web and energy flow patterns in ecosystems [19]. In a 1997 study, juvenile chum salmon and chinook salmon were caught at transplanted and natural reference sites at several locations on the outer Fraser River estuary. Using the carbon isotope ($\delta^{13}C$) as an index of food availability, there was no statistically significant difference between the concentrations of the isotope in chum salmon fry tissue caught at transplanted and reference sites. ($P>0.05$) (Fig 1). These data suggest chum salmon at the restored sites are obtaining carbon from the local food source and that the signature was similar to the natural sites. Chinook salmon fry, which are known to have a broader spectrum of stable carbon signatures in the Strait of Georgia [20], showed a tendency to rely more on marine pelagic food with a less depleted carbon signature (Fig 2). Differences in isotope concentrations for this species between transplant and natural sites were statistically significant ($P<0.05$).

F. Recommendations and merging problems

Systematic and long term geophysical and ecological studies are needed to provide data to assist in the planning of restoration at the Fraser River estuary. Results presented herein were mostly from opportunistic projects that provided only pieces of the puzzle. Modern methods such as stable isotope analyses need to be incorporated into restoration projects. Below ground biomass is another factor that should be monitored, as well as others that provide an assessment of ecosystem functioning. [21] With the new emphasis on restoration of biodiversity, in addition to productivity, restoration planning will become more complex, will require planting of assemblages rather than single species [21], and will require decade scale monitoring to assess projects.

Alien plant species are highly opportunistic and can quickly colonize open spaces such as transplant sites. Over 100 alien aquatic organisms, including 54 species of vascular plants, have been identified in the Strait of Georgia and the Fraser River estuary, and the number of alien species arriving in the region is increasing [22] Alien species such as purple loosestrife (*Lythrum salicaria*) in the Fraser River estuary, can be very difficult to control [23]. Detritus originating from *L. salicaria* is not functionally equivalent to that produced by endemic species [24]. If alien species invade transplant sites, immediate effort is needed to eradicate them.

Creation of habitat for fish predators is another problem that needs attention in the planning of estuarine restoration. For example, if sand island habitats are not completely submerged at high tide, they create nesting and roosting habitat for fish-eating birds such as the Caspian Tern *(Sterna caspia)*. These birds are major predators on endangered salmon species in the Columbia River estuary where they have taken advantage of the habitat developed on dredge spoil islands [25]. Caspian terns occur on the Fraser River estuary in low numbers at present, but caution is needed to avoid enhancement of their habitat.

One of the major future problems for habitat restoration is the possible role of climate change, particularly sea level rise. If water levels and wave energy increase on the Fraser River estuary, most of the geophysical data (e.g. elevations, sediment erosion regimes) currently used for planning restoration will become inapplicable. A multidisciplinary study to help forecast effects of climate change on the estuary was recently implemented [26]. Results should assist estuary planners, such as those associated with the Fraser River Estuary Management Program [27,] to more readily adapt to future changes.

VI Acknowledgments

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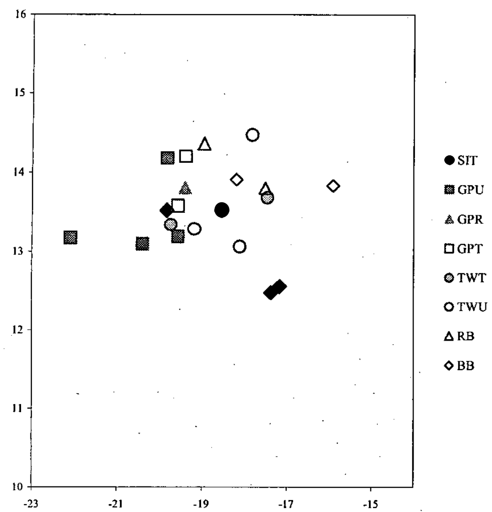


Fig. 1 Stable carbon ($\delta^{13}C$) (x axis) and nitrogen ($\delta^{15}N$) (y axis) isotope signatures in chum salmon collected from Tsawwassen, 1997. Data shown are mean values from individual fish samples (n=3-5) SIT, GPT, and TWT are transplanted marsh sites on Sturgeon and Roberts Bank, Fraser River estuary. Other sites are reference locations. Data from [27]

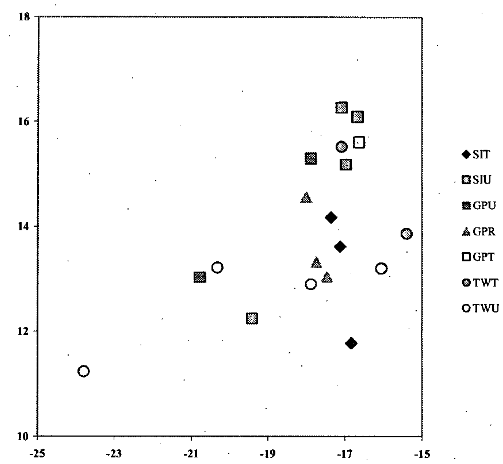


Fig. 2 Stable carbon ($\delta^{13}C$) (x axis) and nitrogen ($\delta^{15}N$)(y axis) isotope signatures in chinook salmon collected from Tsawwassen, 1997. Data shown are mean values from individual fish samples (n=3-5). SIT, GPT, and TWT are transplanted marsh sites on Sturgeon and Roberts Bank, Fraser River estuary. Other sites are reference locations. Data from [27]