Juvenile Salmonid Use of Habitats Altered by a Coal Port in the Fraser River Estuary, British Columbia

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Juvenile chinook, chum, and pink used habitats modified by a coal port at the Fraser estuary in southwestern British Columbia, Canada. Recent construction for expansion of the port has obliterated feeding areas, invertebrate communities, and possibly herring habitat from the local production system. Further studies are required to document recolonization of disturbed habitats and to investigate if present food webs are similar to those before construction. Juvenile salmon may be diverted by causeways and terminals and this also requires study.

The proposed expansion of the Roberts Bank coal port on the Fraser River estuary, British Columbia (Fig. 1) was reviewed by an Environmental Assessment and Review Panel (EARP) using the process described by Waldichuk (1983). The proponent received permission for a limited expansion from 22 ha to 112 ha of fill (Waldichuk, 1983). As new data on fish distribution were not obtained as part of the EARP process (Anon, 1977) acquisition of further data on fish use was required to provide baseline information to help assess effects. Preliminary studies, undertaken well before the EARP exercise, showed the juvenile salmon were using the high tide habitats between the Westshore Terminals loading facilities (built 1969 and handling 12x106 t yr-1 before expansion) and the Tsawwassen Ferry Terminal causeway (built 1960) (Goodman, 1975). In addition, there are few data in the literature examining salmon use of areas affected by port development and hence the data may be of more general interest.

This report presents the results of recent investigations on the ecology of juvenile salmonids that were conducted in 1980 and 1981 on Roberts Bank. Original data are presented elsewhere (Conlin et al., 1982) and show catches of all species from March 1980 to July 1981. Comparisons of conditions and catches during and after construction are also made, using data that were obtained during ongoing dredge monitoring programme (Archibald & Bockings, 1983; Archibald, 1983). Recommended studies are proposed to evaluate longer term effects of port construction on fish habitats.

Description of the Study Area

Roberts Bank is on the south western flank of the seaward portion of the Fraser estuary in southern British Columbia. The area between the causeways is characterized by a flat slope of approximately 1:1000. The geology, flora and macrofauna of this area has been well described by Swinbanks (1979), who documented four major floristic zones: the saltmarsh, algal mat, sandflat, and eelgrass (Zostera marina) (Fig. 1). Another species of eelgrass (Z. japonica) also occurs in the sandflat and eelgrass zones. Mean density of eelgrass on a transect across Roberts Bank between the causeways at about 1.0 m elevation was 136 shoots m⁻² in July 1981 (Levings, unpublished data).

All the shorelines sampled in 1980–1981 were either disrupted by past construction or were man-made beaches due to port construction. A borrow pit used to obtain sand for construction of the original Westshore coal loading facility is an important feature of the intercauseway habitats. Shorelines around the pit were...
extremely steep (>60°), and erosion currents have cut dendritic channels into the eelgrass (*Zostera marina*) beds on the northeast side of the feature (Fig. 1a). Stations on the east side of the Westshore Terminals were characterized by cobble (up to 10 cm), with sand and eelgrass at lower elevations in natural or recovered habitat. Stations on the west side of the Tsawwassen Ferry Terminal were also on cobble. Eelgrass densities adjacent to the man-made cobble beaches were described as patchy by Swinbanks (1979).

Results of temperature, salinity, and dissolved oxygen determinations from 20 cm depth are given by Conlin et al., (1982). Temperatures ranged from lows of close to 4°C in winter to maximum values of approximately 20°C in early June. Dissolved oxygen ranged from 9 to 16 mg l⁻¹, with maximum values in spring. Mean values for percent saturation of dissolved oxygen were 166% and 165% for 1980 and 1981 respectively. Oxygen supersaturation was probably attributable to high primary production of eelgrass and associated algae. Salinity fluctuated from a maximum of about 27‰ in March 1980 and minima of 19‰ and 15‰ during the freshests of 1980 and 1981, respectively (Fig. 2).

Expansion of the Westshore Terminal facility in 1981 and 1982 has resulted in further disruption and modification of both intertidal and subtidal habitats (Fig. 1b). About 115 ha of intertidal and shallow subtidal habitats were permanently filled in, and a further 95 ha dredged to −12.2 m or −20.8 m below chart datum. In addition, an attempt was made in 1982 to prevent further erosion through eelgrass beds by placing a rip-rap ‘key’ around the landward perimeter of the borrow pit (Fig. 1b). Finally during the dredging in 1983 silt spilled off the northwest corner of the expanded site and affected approximately 62 ha of eelgrass in this sector.

**Methodology**

A 14.7 m beach seine was used, with 4.9 m wings (1 cm stretched mesh), bunt 4.9 m (3 mm mesh), and depth 3.5 m. Except at stations where the beach gradient was very steep, where outboard motor boats were used, the net was deployed by personnel wearing chest waders. The distance the net was pulled off the beach and subsequently retrieved varied from about 5 to 10 m. Station locations are shown in Fig. 1a.
Samples were obtained at most of the sites approximately every 2 weeks, except during the winter months when weather and darkness prevented frequent trips. Because of changes in tidal levels, it was not possible to sample all stations at a location on every trip. However, at least three replicate seines were obtained at key locations, especially station 1, on each sampling session. In addition, an intensive beach seineing programme was conducted in June 1981 for mark/recapture experiments (Levings et al., 1983). Complete information on stations sampled, dates, and times is presented elsewhere (Conlin et al., 1982; Levings et al., 1983). A sample of 20 or fewer salmonids, especially chinook, were retained from each catch in the regular seining, and additional fish were counted and released. Retained fish were fixed in 10% formalin and then transferred to 50% isopropanol.

Measurements of lengths and weights were usually completed within 2 months of the sampling. Some length data for chinook from a preliminary survey in 1979 (Greer et al., 1980) are also given.

Diet analyses were conducted by removing the stomach contents from 5–10 chinook from each sample. Invertebrates were then sorted and identified to the lowest taxon possible. Prey items were dried at 100°C for 4 h and then weighed on a Perkin–Elmer electrobalance to the nearest mg.

Results

Catch pattern and size distributions

a. Chinook (Oncorhynchus tshawytscha) (Fig. 3). Chinook were first caught in beach seines in late March 1980 and were consistently taken until mid-August of that year. In early March 1981 chinook fry reappeared and the species was caught until August once again (Macdonald, 1984). Maximum mean abundance recorded for chinook was about 20 fish per set (Fig. 3). Higher catches of chinook (up to 100 per set) were recorded at Station 1A, on the southeast corner of the Westshore Terminal, during seining for fish to use in marking experiments in June 1981. Catches appeared to be higher on incoming tides at this location.

Both fry and smolt-sized chinook were obtained on Roberts Bank, as shown by data obtained in 1979, 1980, and 1981 (Fig. 4). In June, for example, usually several modes in length were observed, one at 40–50 mm, one at 60–70 mm, and another at 80–90 mm (Fig. 4). Length modes in other months were highly variable, and estimation of growth rates by changes in mean lengths was not possible.

Condition factors (KF) for chinook on Roberts Bank were extremely variable in both 1980 and 1981, and there was no evident trend in values of KF with fish size.

b. Chum (O. keta). Chum fry were first taken on Roberts Bank in late March 1980 and were caught until mid-June. Catches in 1981 extended through to July. Maximum mean abundance during the low tide work was about 10 fish per set, but this is a definite underestimate, as much larger catches (up to 1000 chum per set) were obtained at station 1 during seining for mark-recapture work (Levings et al., 1983). Chum catches appeared to increase with incoming tidal flows at this site, and a moderate current (25–50 cm s⁻¹) was observed moving around the southeast corner of the terminal. This current,
Chinook diets

Gut contents of chinook were examined in some detail for fish from 1980, using specimens collected from April to August. From 73 fish, the following invertebrates were identified: calanoid copepods—3 taxa; harpacticoid copepods—at least 4 taxa; gammarid amphipods—5 taxa; cumaceans—7 taxa; mysids—3 taxa; insects—7 taxa, and fish—5 taxa. The representation of major food items in stomachs changed during spring and summer 1980 (Fig. 5). In April and May, epibenthic crustaceans (harpacticoi, amphipods) and adult insects were most prevalent, whereas fish remains (primarily herring (Clupea pallasi)) dominated in later months.

Residency

During 1–5 June 1981, marking experiments using fluorescent grit were conducted in the intercauseway area to examine short-term residency. Complete details are provided in Levings et al., (1983).

Relatively small numbers of fish were released (est. 515 chum and 1733 chinook), but a few marked individuals of both species were recovered after 2 days (Levings et al., 1983). This indicated some residency and, surprisingly, incomplete dilution of local populations by fish moving in from offshore into the study area. Marked chinook were recovered only at the stations along the seaward boundary of the borrow pit, close to the eelgrass habitats where they were released. Marked chum, on the other hand, were only caught on the cobble beach on the northeast side of the Westshore Terminal (Fig. 6).

Marked chinooks were recovered from the intercause-

which has also been observed in hydraulic model studies of the port (WCHL, 1981), may have brought fish from offshore into the embayment off station 1.

Chum from May in both 1980 and 1981 showed modal length of 40 to 50 mm. In June 1981 most fish were between 50 and 65 mm in length, although some individuals >90 mm were caught (Levings & Gordon, 1984).

c. Pink (O. gorbuscha). Pink were taken at Roberts Bank only in 1980, in accordance with their known cycle of even year outmigrations on the Fraser. This species was caught only in late April and mid-May. Maximum mean abundance was about 30 fish per set at the latter date. Pink from Roberts Bank in May 1980 showed length modes at 40 to 57 mm with some individuals >80 mm recorded. Fish taken in June 1980 showed a relatively distinctive mode at 50 to 60 mm (Gordon and Levings 1984).

d. Coho (O. kisutch). Coho were apparently rare at low tide on Roberts Bank and only 29 were taken in the intensive sampling (101 hauls) for marked fish in June 1981. Coho from 1981 were all smolt sized (>80 mm) (Levings et al., 1983). None was caught in the 1980 sampling.
way area in late July–early August 1981 (4 fish) (DFO, and A. Macdonald, unpublished data) and mid to late June 1982 (4 fish). The 1981 fish were released from the Chehalis hatchery (Harrison River system) in May. In 1982, smolts originated from the Chehalis and Chilliwick hatcheries, and were released in March 1982. These data show that smolt-sized chinook from hatcheries use Roberts Bank habitats, but further data are required on whether or not these stocks are migrating through or reside in the intercauseway area.

Discussion and Recommended Studies

Results from the present studies show that low tide use of Roberts Bank habitats by juvenile salmonids is extensive. Chinook use can extend from March to August, and the other species are found in abundance for relatively shorter time periods. Residence times for chum and chinook were less than reported by Levy & Northcote (1982) for brackish marshes elsewhere in the Fraser estuary, but we released fewer fish and were working in a much larger area. Work conducted subsequent to July 1981 has included further detailed sampling to examine differences in fish use among eelgrass, sandflat, and channel habitats in the intercauseway area (Macdonald, 1984). Other surveys using both beach seines and purse seines were conducted during dredge monitoring in 1982 and 1983 (Archibald, 1983; Archibald & Bicking, 1983). This work provides confirmation that catches of juvenile salmon in the intercauseway area were similar to the present study and related work elsewhere in the Fraser estuary (e.g. Greer et al., 1980; Levings & Gordon, 1984). The recent construction has apparently not diverted fish from the area, but has obliterated feeding areas, invertebrate communities, and possibly herring habitats from the local production system. Herring may occasionally spawn in eelgrass on Roberts Bank, but it is thought that the juvenile herring originate from areas a few kilometres east, where spawning is more regular (Gordon & Levings, 1984). Early survey of invertebrates in intact eelgrass beds on Roberts Bank showed considerable biomass of potential macrobenthic food organisms (Levings & Coustain, 1975). A seasonal study of meio-benthic organisms, including harpacticoids, at station 1 showed these food organisms were in peak abundance when salmon used the nearshore habitats (Fig. 7). Chinook fry and smolt used these invertebrates and diets were as described by other authors who worked in other B.C. estuaries with eelgrass beds such as the Nanaimo estuary (e.g. Healey, 1980).
As described above, since our studies were completed dredging and filling for port construction (1982, 1983) has severely modified the intercauseway habitats as follows:

1. Cobble beach habitats at Stns. 1, 2—obliterated by construction (est. 2 ha), but replaced on the north side of Site 4 (Fig. 1).

2. Eelgrass habitats at Stns. 3, 4, 5, 6—modified by construction of an 'erosion control structure' or rip-rap key around the inshore portion of the borrow pit. Water now pools behind the rip-rap at low tide and eelgrass seaward of the key appears to be suffering from desiccation (Harrison, 1983). There has also been loss due to dredging for the turning basin (Moody, 1983) (Fig. 1b).

3. Sandflat habitats obliterated by construction (est. 115 ha; Archibald, 1983; Moody, 1983).

4. Subtidal habitats seaward of Stns. 3, 4, 5, 6—deepened and modified by dredging for turning basin (est. 95 ha; Moody, 1983) (Fig. 1b).

It is obvious that damaging habitats by filling for port facilities has rendered certain of the habitats in the intercauseway area totally unusable by fish. Other modifications are more subtle and further studies are required to establish changes in fish use. The following are some suggestions where this work could be conducted. Further studies should emphasize comparisons with undamaged habitats elsewhere on Roberts Bank.

**Towboat Mooring Basin (northeast side of new fill area)** (Fig. 1b).

A small area of shallow water habitat has been gained by dredging for towboat mooring (Fig. 1b). This is an analogous site to our stations 1 and 2 from 1980 and 1981, having a similar embayed configuration and possibly similar depths. The deep water habitat gained by dredging is not usable by juvenile salmonids, especially fry, since it has been established that juvenile chum and chinook use the shallow upper layers of the water column (Archibald, 1983). Archibald (1983) and Archibald & Bocking (1983) beach seine in this area in 1982 and 1983 and found catches were comparable to those from before construction, indicating chum and chinook used these disrupted areas. However, food habits were not studied. Since the original habitats have been obliterated, it would be of interest to establish if colonization has been completed in the new area and to determine if salmon diets changed.

**Intertidal areas**

Juvenile salmon use of the new shorelines in the area of the port requires further detailed studies. Shorelines have
been created around the perimeter of the new facility, but most are steep and consists of large angular rip-rap or vertical pilings. Some invertebrates that colonize these surfaces might be usable as food by juvenile salmon (Miller & Hensel, 1982). It would also be worthwhile to investigate fish use of the borrow pit and new dredged turning basin. Macrophytic algae, including bull kelp (*Nereocystis lutkeana*) has established on the erosion control structure since the rip-rap was put in place in spring 1982. It is not known if this new algal habitat or food produced in it is used by juvenile salmonids.

**Causeway effects**

Some fish migrating to the southwest from the mouth of the Fraser River might have been deflected seaward by the Westshore Terminal structure, where they would be more susceptible to predation by larger salmonids (e.g. coho). Data on migration routes are required. The smaller fish may in fact be attracted to the shallower habitats along the causeways and move along the perimeters of the structures. The longshore migration of a number of adult Arctic fish (e.g. ciscoes, *Coregonus sardinella*, *C. autumnalis*; arctic char, *Salvelinus alpinus*) was modified by a 3.9 km causeway near Prudhoe Bay in Alaska (Critchlow & Moulton, 1983). Previous studies (e.g. Craig & Griffiths, 1981) also showed differences in temperature and salinity attributed to this causeway. Both Critchlow & Moulton (1983) and Craig & Griffiths (1981) suggested that fish distribution can be affected by differences in water mass distribution. Swinbanks (1979) showed generally higher salinity water in the intercauseway area on Roberts Bank compared to the river side of the structure, but our data show that freshening can occur in the intercauseway area (Fig. 2). Fish travelling in patches of brackish water might therefore move occasionally into the intercauseway sector as wind, river discharge, and tidal conditions permit. Before the causeway was constructed brackish water was more uniformly distributed over southern Roberts Bank. Further detailed sampling is required to investigate this aspect of juvenile salmon distribution.

**Conclusions**

Juvenile salmonids used disrupted and man made habitats at a coal port on Roberts Bank, Fraser River estuary. Chinook (*Oncorhynchus tshawytscha*) and chum (*O. keta*) resided between the port causeways. Chinook fed on invertebrates, especially harpacticoids, produced in eelgrass (*Zostera marina*) and sandflat habitats.

Recent construction for expansion of the coal port has resulted in obliteration of shallow water habitats by filling and dredging. Further studies are required to examine feeding habits of salmon in the recently disrupted area.

Some invertebrate and algal habitat has been created by placement of rip-rap along the port shorelines and at an erosion control structure. Data on fish use of these habitats are required, as are investigations into the influence of causeways on fish migration.

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Goodman, D. (1975). Fisheries resources and foodweb components of the Fraser River estuary and an assessment of the impacts of proposed expansion of the Vancouver International Airport and other developments on these resources. Dept. of Environment, Fisheries and Marine Service, Vancouver, B.C. 134 p + appendices.


