E.2. Electronic Appendix - Food Web Elements of the Fraser River Basin

Upper River (above rkm 210)

Food webs: Microbenthic algae (periphyton), detritus from riparian vegetation and littoral insects (especially midges) are key components supporting fish production in the mainstem upper Fraser and larger tributaries. Collector-gatherers (invertebrates feeding on fine particulate organic material) are the most abundant functional feeding group, making up to 85% of the invertebrate species on the latter two rivers. Smaller tributaries are dominated by collector, shredder and grazer insect feeding modes (Reece and Richardson 2000). There is a general increasing trend in insect abundance from the headwaters of the main river to the lower river (Reynoldson et al. 2005). Juvenile stream-type Chinook rear along the shorelines of the upper river and tributaries and some overwinter under ice as the river margins usually freeze over here. Juvenile Chinook diets in the main stem and tributaries include larval plecopterans, empheropterans, chironomids and terrestrial insects (Homoptera, Coleoptera, Hymenoptera and Arachnida; Russell et al. 1983, Rogers et al. 1988, Levings and Lauzier 1991). Rainbow trout and northern pikeminnow consume mainly sculpins in the Nechako River as well as a variety of insects (Brown et al. 1992).

Stressors: Water quality and habitat conditions have changed food webs in specific locations in the upper river. However, compared to other rivers in North America, water quality is good (Reynoldson et al. 2005), even with five pulp mills currently operating in the megareach. The food web of the Thompson River was stimulated in the past by low concentrations of bleached Kraft pulp mill effluent released into the river (Dube and Culp 1997); it is not known if this is still happening as treatment techniques for effluent have changed. Dioxin in juvenile Chinook was detected in the 1980s (Servizi 1989, Rogers et al. 1988). Surveys in the mid-1990s found significant concentrations of contaminants in a few locations, but improvements at pulp mills and waste water treatment plant upgrades are thought to have improved water quality (Gray and Tuominen 1999, Macdonald et al. 1998). Legacy contaminants such as PCDDs, PCDFs, and PCBs were recorded in white sturgeon in the late 1990s and presumably are still present in these long-lived fish (MacDonald et al. 1997). Carcasses from spawning sockeye bring persistent organic pollutants to the upper river (Kelly et al. 2007). Logging has impacted the temperature regime and likely the productivity of insect communities (Patterson et al. 2003) in smaller tributaries, especially in the far northwest tributaries of the upper river where boreal forest trees, including those affected by the invasive mountain pine beetle, are harvested. To date about 8 M ha have been affected, ~ 35% of the drainage area (Schnorbus et al. 2009), but specific investigations of food web effects of logging the infected trees have not been reported.

There are no hydroelectric dams on the upper mainstem Fraser River. However, three tributaries (Nechako, Seton, Bridge and Shuswap Rivers) have a total generating capacity of 1,435 MW. Flows vary significantly on the Nechako River when water released from a storage reservoir (see below) is used for power or to maintain temperatures for migrating salmon; 20° C is the target temperature to be maintained (NFCP 2010). The consequences of these fluctuations for food webs have not been quantified. Riparian zones and water quality on the upper Fraser and tributaries have been modified by logging, urbanization and agriculture (e.g., Thompson River; Bradford and Irvine 2000) but effects on riparian food webs have not been evaluated. There are approximately 581 licensed irrigation dams (72%

of those in the whole Fraser Basin)[1] on tributaries in this megareach with widely varying storage capacity (Birtwell et al. 1988). The only non-native species present are brook trout (stocked in tributaries; Freshwater Fisheries of Society of BC 2010), yellow perch (Johnson 2009), and goldfish and carp (McPhail 2007; Table E.2.A).

Table E.2.A**.** Non-native fish species in three megareaches of the Fraser River. Key: + rare, + + modestly common, + + + common. Abundance data from McPhail 1998. n.a. – not applicable.

Common Name	**Estuary**	**Lower River**	**Upper River**	**Comment**	**Reference**
Atlantic salmon	+	+	-	Not established	McPhail 2007
Black crappie	+ +	+ +	-	Established	McPhail 2007
Brook trout	-	+ +	+ +	Stocked and established	Freshwater Fisheries Society of BC 2010
Brown Bullhead	+ +	+ +	-	Established	McPhail 2007
Carp	+ +	+ + +	+ +	Established	McPhail 2007
Fathead minnow	-	+	-	Established	McPhail 2007
Goldfish	-	+	+	Established	McPhail 2007
Lake trout	-	+	NA	Transplanted from upper river where it is a native species	McPhail 1998
Lake whitefish	-	+	NA	Transplanted from upper river where it is a native species	McPhail 1998
Largemouth bass	-	+	-	Established	Brown et al. 2009
Pumpkinseed	-	+ +	-	Established	McPhail 2007
Shad	+	+	-	Not established	Pers comm., John Davidson DFO, April 6 2010
Yellow perch	-	+	+	Established	Johnson 2009 Brown et al. 2009

Restoration: Fertilization experiments showed that the basal elements of the Nechako River's food web could be stimulated by addition of nitrates and phosphates, but the effects did not propagate into higher trophic levels (Perrin and Richardson 1997, Slaney et al. 1994). Decisions to improve water quality are hampered by knowledge gaps regarding the effects of contaminants on food webs and fish health in the upper river. In particular, lacking are 1) an understanding of the cumulative effects of low levels of pollutants and 2) the knowledge needed to specify thresholds for site-specific toxicity in water quality guidelines (Gray and Tuominen 1998).

[1] A summary listing the capacity of the irrigation WSRs in the Fraser Basin was not available for this review. However to give some perspective on their size, Northcote (1997) mentioned that an atlas by Chapman and Turner (1956) listed 200 irrigation dams, each of storage >123,000 m^3 (0.1 M m^3) concentrated in the drier central and southeastern parts of the upper river megareach.

Lakes[2]

Food webs: The Fraser River sockeye lakes have been studied intensively in support of management efforts to understand carrying capacity (Hume et al. 1996). These food webs are now known to be supported at the basal level by very small phytoplankton and microbes (Stockner 1994). Chinook and coho rear on the shorelines of lakes connected to Fraser River tributaries (e.g., Shuswap Lake; Graham and Russell 1979) and are likely consumers of this fauna. Cladocera, chironomidae (larvae), ostracods, oligochaeta, calanoida and nematoda are the most numerous invertebrates along the shoreline of Shuswap Lake (Brown et al. 2004).

Stessors: These include water withdrawal for irrigation in drier parts of the Basin (e.g., Thompson River system; Bradford and Irvine 2000). The recent appearance of non-native yellow perch in Shuswap Lake, an important sockeye producing system, may lead to a hybrid web (Johnson 2009). Non-native milfoil has likely changed the basal food web in numerous lakes, including Shuswap. The creation of a large water storage reservoir (890 km^2) on the upper Nechako River system (see above) resulted in the obliteration of several natural lakes and has been an ecological concern since its formation in 1951 for hydro power generation.[3] Fish at upper trophic levels in the food web of the reservoir have become contaminated with heavy metals, especially mercury (Northcote and Atagi 1997). Long range transport of contaminants in lake ecosystems and bioaccumulation into burbot was found in Moose Lake, the headwaters of the Fraser River (Macdonald et al. 1999).

Restoration: This has focused on nutrient addition to several lakes to boost fish production. Chilko Lake was fertilized from 1990 to 1993 and Adams Lake was fertilized in 1997 (Hyatt et al. 2004). In both cases, the objective was to improve the growth and survival of sockeye fry, and by producing larger smolts, to increase subsequent survival during downstream and seaward migration. Despite some evidence of success (Bradford et al. 2000), both programs were discontinued. Two other dammed lakes in tributaries to the lower Fraser River Basin, Alouette Lake (Harris et al., in press) and Wahleach Lake (Perrin et al. 2006), are being fertilized to improve fish production (including kokanee) to mitigate for the impacts of hydropower development.

Lower River (rkm 78-210)

Food webs: Twenty-one fish species are reported in this megareach (Church et al. 2009) and most rely on aquatic insects for sustenance. Caddisflies (Hydropsychidae), predaceous stoneflies (Perlodidae), grazing mayflies (Heptageniidae) and detritivorous stoneflies (Capriidae and Tanaeinopterygidae) are the most common insects in the littoral zone of the lower river. Functional modes of feeding by the insects indicate strong links to periphyton and detritus. Highest density of collector-gatherer insects occurs at depths of 0.2 - 0.5 m where hydraulic stress is lowest. Juvenile Chinook overwinter in the same reach and are likely predators on the aquatic insects then as well as in other seasons (Levings and Lauzier 1991, Richardson and Levings 1996, Rempel et al. 2000, Reece and Richardson 2000).

Stressors: Gravel extraction for construction and flood control in the lower river removes basal and secondary food web elements, which raises concern about its effects on riparian food webs as well

[2] Most of the large lakes in the Fraser River system are at the headwaters of tributaries in the Upper River but there also a few on tributaries to the estuary.
[3] Water is diverted from the water storage reservoir (WSR) to the plant via a 16 long km tunnel through the coastal mountains.

(Rempel and Church 2009). Loss of riparian habitat on tributaries has also resulted from urbanization, farming and logging leading to reduced food supply from vegetation (Anon 1998). There are 13 non-native fish species, of which two were native species transplanted from the upper river into lakes (lake trout and lake whitefish; McPhail 1998; Table E.2.A). Dioxins, furans, chlorophenolics and PCBs were found in benthic invertebrates in the 1990s (Richardson and Levings 1996).

Restoration: Restoration has focused on smaller tributary streams, and appropriate restoration strategies are based on analysis of factors limiting salmon productivity to identify appropriate restoration strategies (Foy 1997). Often riparian habitat is restored in an effort to increase detrital flux and insect productivity but food web effects have not been evaluated.

Estuary (mouth to rkm 77)

Food webs: These have been studied extensively and are known to be supported by detritus, which is thought to originate mainly from the ribbon marshes in the tidal portions of the lower river. Research has not distinguished between macro- and micro-detritus as has been done in the Columbia River estuary. Direct grazing on benthic microalgae on sand flats is also a major food web pathway (Pomeroy and Levings 1980). Additionally, the eelgrass food web on Roberts Bank, the southwest flank of the outer estuary, is important to juvenile salmon. Harpacticoid copepods, with links to diatoms growing on eelgrass as well as detritus, are a key food of juvenile salmon there (Webb 1991).

No documentation exists for the estuary (unlike the Columbia River estuary) to indicate how detritus entering from upstream is incorporated into food webs. The estuarine system exhibits strong linkages to a common food base for large scale suckers, three-spine sticklebacks, Chinook, peamouth chub, starry flounder, white sturgeon, northern pikeminnow, prickly sculpin, staghorn sculpin, bull trout, redside shiner, and sockeye salmon All species in the estuarine assemblage are linked via a variety of epibenthic invertebrates (mainly amphipods, mysids, chironomids, and other insects) to benthic detritus, while several species are also linked with zooplankton (cladocerans, cyclopoids, harpacticoids; Northcote et al. 1979, Kistritz 1983, Healey and Richardson 1996, Levings 2004; Figure A).

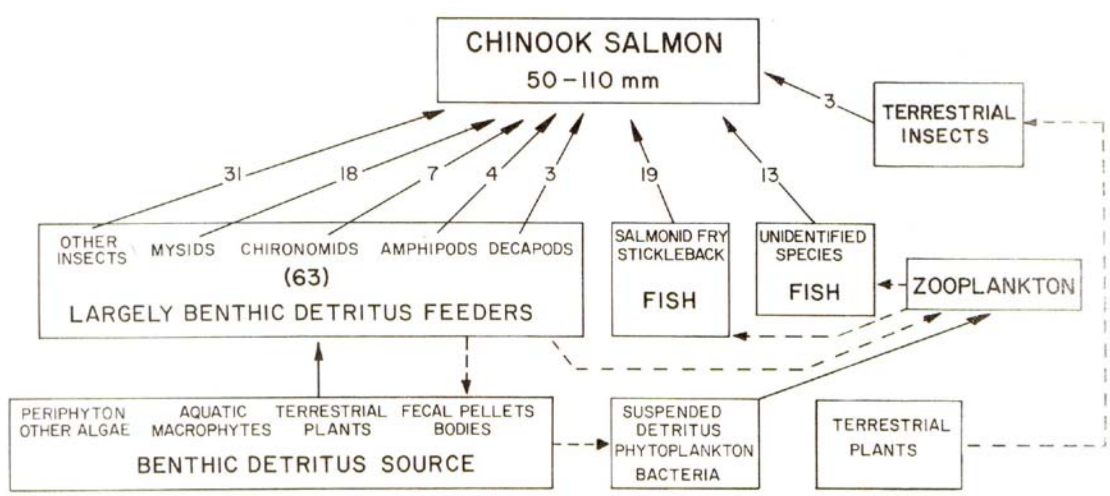

Figure E.2.A. Food web for juvenile Chinook in the Fraser estuary. Numbers on lines connecting Invertebrates to Chinook are percentages that various taxa accounted for in Chinook stomachs. From Northcote et al. (1979).

It is instructive to compare the abundances of 37 fish species in the lower river documented in studies in 1972-1973 and 1993-1994 (Richardson et al. 2000). Despite changes in the lower Fraser River ecosystem over the 21 year interval, especially from habitat loss as the numbers of humans and domestic livestock have both nearly doubled in the catchment, the overall fish community showed remarkably little change. Strong rank correlations of species abundance or biomass indicated that the overall fish community structure is similar during both periods with peamouth chub, largescale sucker, starry flounder and northern pikeminnow dominating the fish community. However, at smaller spatial scales (reaches of 2–3 sites, equivalent to about 20-50 km)) and shorter time scales (by season), less than half the comparisons showed any significant correlation indicating changes in community composition were localized.

Insect communities in tributaries to the estuary are dominated by collector, shredder and grazer insect feeding strategies. Cutthroat trout, rainbow trout and juveniles of coho, chum, and Chinook are some of the fish species at the top of the food web here (Levings 2004).

Stressors: Most authorities estimate that 70-90% of the former wetlands in the estuary have been lost by diking and urbanization (Levings 2004). Further, it has been estimated that wetland vegetation in the lower 160 km of the watershed (includes part of the lower river as per above definition) once provided about 2.5 times more organic carbon than at present (Healey and Richardson 1996). Eelgrass beds have declined due to port construction but one bed has grown larger (Harrison and Dunn 2004). Purple loosestrife, a non-native wetland species, is present but detritus from this plant does not provide as much in the way of nutrition when compared to native sedges (Grout et al. 1997). At least six non-native fish species – carp, pumpkinseed, brown bullheads, brook trout, fathead minnow, black crappie – have become established, mostly in the lower river and estuary (Table E.2.A). Shad and Atlantic salmon have been recorded but are not considered established. Brown bullhead is a minor consumer of juvenile salmonids (Gregory and Levings 1998). Peamouth chub and starry flounder, two indicators species in the estuary, have bioaccumulated dioxins, furans, chlorophenolics and PCBs via the food web (Vingarzan and Sekela 2004).

Smaller tributaries to the estuary have water storage reservoirs with a hydroelectric generating capacity of 269 MW.

Restoration: Food web restoration for basal elements supplying detritus has focused on transplanting marsh vegetation; 42 sites of widely-varying areas (77 -15,000 m^2) were restored up to 1997 (Adams and Williams 2004)[4]. An experimental program to spill water from two water storage reservoirs on estuary tributaries precipitated outmigrations of "sea-run kokanee" in the Alouette and Coquitlam rivers (2005 to present). The outmigrations have resulted in anadromous returns of adult sockeye to both rivers for the first time (2007 to present) since the original anadromous runs were extirpated by dam construction about 90 years ago (Godbout et al. accepted manuscript).

[4] In most instances these transplants were compensation or creation projects for habitat lost as per Fisheries and Oceans Canada's "no net loss" policy (Adams and Williams 2004).

Plume (seaward of the mouth)

Food webs: The plume is a key component of the Strait of Georgia, the inland sea that receives the freshwater of the Fraser River. Discharge from the Fraser River is, like the Columbia River, a major physical driver for the plume. Also like the Columbia, there is concern that the decreasing trend in runoff, owing to climate change (Morrison et al. 2002), is modifying the pelagic ecosystem. Plume fronts are especially important for phytoplankton and zooplankton (Parsons et al. 1970). It is these locations where turbid waters from the river mix with ocean water. Nutrient levels and phytoplankton and zooplankton production are key factors for salmon feeding. More recent research has shown the complexity of interactions between discharge, nutrient upwelling, winds and ocean circulation (Collins et al. 2009).

Stressors: Climate change and contaminants are some of the factors which may be changing food web dynamics in the plume although few long term data are available. Contaminants enter the plume through long range transport and local discharges. Contaminants in Fraser River water are transported seaward into the plume and may remain in the surface layers because of the buoyancy of fresh water. *Orcas* are an example of a higher level predator which bioaccumulate organic contaminants in this region, possibly via salmonids which are part of their food web (Johannessen and Macdonald 2009).

Restoration: Recovery for climate change impacts in coastal waters can only be achieved by international efforts to control greenhouse gas emissions, as explained in ISAB (2007). Decreases in contaminant levels in plume waters are dependent on pollutant management in the Fraser River, other adjacent streams, and regions where chemicals moved by long range atmospheric transport originate.