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Review of potential critical habitats for white sturgeon (*Acipenser transmontanus*) in the Fraser River estuary.

Revue des habitats critiques potentiels de l'esturgeon blanc (Acipenser transmontanus) dans l'estuaire de la rivière Fraser.

C.D. Levings and W.A. Nelson

Fisheries and Oceans, Science Branch,
West Vancouver Laboratory,
4160 Marine Drive,
West Vancouver, BC V7V 1N6

And

Dept of Biological Sciences,
University of Calgary.
Calgary, Alberta
T2N 1N4

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Abstract

In this paper we review metrics and methods to assess potential critical habitat for white sturgeon (*Acipenser transmontanus*), a species which was formerly abundant in the Fraser River estuary in British Columbia. White sturgeon are listed with COSEWIC as a species of Special Concern. We also review the sparse literature on the environmental requirements of white sturgeon, discuss past and present threats to the species' habitats, and provide suggestions for research. Several of the existing water quality criteria are based on water column characteristics (e.g. temperature, flow, substrate type, dissolved oxygen, and toxicants), often from laboratory measurements of tolerance. Preliminary results from an age-structured density-independent model for white sturgeon populations and habitats in the lower Fraser River and estuary are presented. The simulations suggested that access, water flow, and sediment exchange between slough and channel habitat are key ecological processes for this species. Metrics for mapping substrate and related biophysical features important for white sturgeon are not well developed. Relationships between habitats and white sturgeon population dynamics are poorly understood. Mapping at the macroscale (1:1 M) showed that about 70 % of estuarine habitat has been lost in the Fraser River estuary owing to urbanization. It is not clear if the remaining habitat in its degraded configuration is sufficient to maintain present or restored white sturgeon populations.

Résumé

Nous avons étudié les paramètres et méthodes d'évaluation des habitats critiques potentiels de l'esturgeon blanc (*Acipenser transmontanus*), espèce qui a déjà été abondante dans l'estuaire du Fraser, en Colombie-Britannique, et qui est maintenant désignée comme « espèce préoccupante » par le COSEPAC. Nous avons également consulté les quelques documents portant sur les besoins en matière d'habitat de l'esturgeon blanc, analysé les facteurs qui ont dégradé ou qui menacent les habitats de ce poisson et proposé des pistes de recherche. Plusieurs des critères actuels relatifs à la qualité de l'eau sont fondés sur les propriétés de la colonne d'eau (température, débit, type de substrat, oxygène dissous, substances toxiques, etc.), et sont souvent déterminés à partir de mesures de tolérance réalisées en laboratoire. Nous présentons ici les résultats préliminaires d'un modèle indépendant de la densité, structuré en fonction de l'âge, des populations et des habitats de l'esturgeon blanc dans le bas Fraser et dans l'estuaire. D'après les simulations, l'accès, le débit de l'eau et les échanges de sédiments entre les habitats marécageux et le chenal constituent des processus écologiques clés pour l'espèce. Les paramètres de cartographie des substrats et des propriétés biophysiques connexes qui sont importants pour l'esturgeon blanc ne sont pas bien développés. Les relations entre les habitats et la dynamique des populations d'esturgeons blancs sont très mal connues. La cartographie à grande échelle (1:1 M) a montré qu'environ 70 % des habitats estuariens du Fraser ont disparu à

cause de l’urbanisation. Nous ne savons pas si les habitats restants, dans leur état dégradé, sont suffisants pour maintenir ou restaurer les populations d’esturgeons blancs.

1. INTRODUCTION

The concept of “critical” or “essential” habitat is not compatible with an ecosystem approach to management of fish habitat because, as described in detail in a previous Workshop (Jamieson et al. 2001), an ecosystem is made of interrelated habitats which function together to maintain ecological integrity. For the purposes of this paper the idea of a "bottleneck" habitat for an ecosystem is perhaps a useful operational definition of potentially critical habitat - "a habitat feature that is necessary to maintain the ecological integrity of an ecosystem and ensure survival of a species at risk in that ecosystem". We mention this definition only to set the context of the linkages between habitats that estuarine fish depend on at various life history stages. Other scientists working in Pacific region have grappled with the concept of "critical habitat” and also had to develop rather arbitrary definitions. For example, Gregyr and Trites (2001) used a probabilistic method and harvesting data to determine whale habitats off the west coast of Vancouver Island and concluded "….while we may debate whether the habitats described are "critical” or "important” of simply "suitable” the areas identified should be acknowledged as having some level of importance to these species" (Gregyr and Trites 2001). However under recently-proclaimed, Species At Risk Act, the term has a strict legal definition: “critical habitat" means that necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species (Environment Canada 2002).

The following outlines how we organized this Research Document to give information and ideas on potential critical habitat for white sturgeon (*Acipenser transmontanus*), as a case history study of an estuarine species. The lower Fraser population of white sturgeon is listed in the red category by the Province of BC (http://srmapps.gov.bc.ca/appsleswp/reports.do?index=3). The species is listed by COSEWIC as a species of special concern and retention of white sturgeon has not been allowed since 1994. As far as known the Fraser River estuary is the only estuary in British Columbia where the species was abundant in the past, as white sturgeon have been rarely observed in any other estuary on the west coast of Canada. The species is relatively well known in the Columbia and Sacramento River estuaries in the United States.

Initially we describe the status of our knowledge of the species' ecology and habitat usage, the status of mapping of its habitat, and past and present threats to survival in the Fraser River estuary. We then outline some of the problems involved in mapping the species' habitat. The final section of the paper gives research recommendations.

2. CAVEATS CONCERNING WATER AS HABITAT AND CONTAMINANTS

In an overarching sense, species at risk need water that is characterized by temperature, salinity, and dissolved oxygen ranges that they are adapted to. Few data are available on the tolerances of white sturgeon adults and juveniles, which are the life history stages using the Fraser River estuary (see below), to these key variables. Almost all of the data are from laboratory experiments on white sturgeon in California. Cultured juvenile white sturgeon (30 g) grew relatively well at 26 °C (Hung et al. 1993), which is well above most of the ambient temperatures found in the Fraser River estuary (Ages and Woolard, 1994). Crocker and Cech (1997) found that white sturgeon (0.2-63.1 g) reacted to hypoxic conditions by reducing metabolism and movement, which the authors stated might be adaptations to habitat conditions. Young adult white sturgeon (2.5-15 kg) were found to tolerate higher salinities (35 ‰) relative to juvenile sturgeon (McEnroe and Cech 1985). However extrapolation of the above results from California estuaries to the Fraser River estuary may be difficult because of genetic differences between populations.

Decreasing water quality from contaminants is an insidious problem that needs to be carefully researched and monitored to protect or restore species at risk. It should be understood that for all aquatic habitat to provide support for the life functions of biota, it needs to be overlain by water that is not toxic nor contains persistent pollutants that can lead to excess body burdens of dangerous chemicals. White sturgeon are potentially affected by toxic chemicals (e.g. dioxins and wood preservatives: MacDonald et al. 1997; Bennett and Farrell 1998). White sturgeon are benthic or demersal fishes and hence are exposed to contaminants in sediments. However because of the complex mixture of chemicals in water and sediments in the Fraser River estuary, a comprehensive review of this aspect is not possible in the present document.

3. STATUS OF KNOWLEDGE: BIOLOGY AND HABITAT

At the peak of the fishery in the late 1890s, about 500 t of white sturgeon were harvested from the lower Fraser River in a single year but catches declined dramatically after that and have not recovered to their historical levels (Fig. 1, Echols 1995). Biologists who have investigated the white sturgeon population dynamics attribute the decline to overfishing (Semakula and Larkin 1968; Echols 1995). The demise of other sturgeon populations in North America have been linked to both overfishing and habitat change (e.g. Collins et al. 2000) but there has been no systematic evaluation or summary of habitats used by white sturgeon in the lower Fraser River.

We provide a comprehensive review below, drawing on the literature available from the reaches downstream of Chilliwack (about river km 100) to the ocean (Fig. 2). For the purposes of this paper, we consider these reaches to encompass the tidal estuary, as water levels within them are affected by the tide (CHS 1994). However, the salt wedge only extends upstream to about Annacis Island (river km 27) (Ages and Woolard 1994). Many data on the ecology of white sturgeon are available upstream from Chilliwack (e.g. RL&L 2000). There is much less published information on the ecology of white sturgeon in the tidal estuary, but there is a substantial data base under development by the Fraser River Sturgeon Conservation Society (FRSCS 2002). RL&L (2000) concluded that the genetically unique population of white sturgeon they sampled between river km 80 (Mission) and river km 150 (Hope) "undoubtedly extends to below Mission". Recent information strongly suggests that the white sturgeon below Hope is a genetically unique unit (Smith et al. 2002).

A combination of r and K traits, including late maturity for this species are probably key life history attributes that has placed white sturgeon at risk. The first major paper on the ecology of the white sturgeon in the lower Fraser was published by Semakula and Larkin (1968). These authors used fin rays as a method of ageing and concluded white sturgeon reached sexual maturity at an advanced age (females: 26-34 y; males: 11-22 y). Although the authors apparently did not recognize it at the time, the late maturity of white sturgeon clearly made the species vulnerable to harvesting and meriting special conservation methods (see Powles et al. 2000).

3.1 Habitat requirements

Until recently data on general macrohabitat requirements for white sturgeon were fishery dependent and the distributional data obtained when the species was most abundant are therefore biased. The fact that green sturgeon (*Acipenser medirostris*) were not distinguished from white sturgeon in all the early fishery data is an additional complication. Where possible, fishery independent data have been used in the description below.

3.1.1 Spawning habitats

Based on field observations and culture studies, most authors are of the opinion that white sturgeon are adapted to spawn in fresh water (Vienott et al. 1999). Perrin et al. (2003) gave data showing the habitat characteristics of certain side channels or sloughs in the upper reaches of the tidal estuary where they observed spawning fish. White sturgeon spawn in main river habitat in the Fraser River above Chilliwack but there is no evidence of main stem spawning in the tidal estuary (M. Rosenau, BC Ministry of Water, Air, and Land Protection, Surrey, BC, personal communication).

Some microhabitat data were provided by Perrin et al. (2003) (Fig. 3). Plots of habitat suitability indices show that preferred spawning temperature was 13-15 ºC, water depth 1-5 m (mean 2.9 m), and velocity > 1.5 m s^{-1} (mean 1.0 m s^{-1} for larvae). Reduced light attenuation caused by natural turbidity may be an important factor at the spawning locations.

3.1.2 Is the species obliged to use brackish water or ocean rearing habitats?

Due to lack of detailed knowledge of white sturgeon life history, we are not certain if the white sturgeon is anadromous or not. Echols (1995) concluded the species was semi-anadromous. White sturgeon are caught in the salmon gillnet fishery in the lower Fraser estuary in the reaches where the salt wedge penetrates (Echols 1995) and the species has definitely been reported from Sturgeon Bank (Lane, Malaspina College, Nanaimo, BC, pers. comm.) where brackish water is prevalent (Levings 1982). Experimental data have shown that Gulf sturgeon (*A. oxyrinchus desoto*) grow more efficiently in brackish water (3-9 ‰) (Altinok and Grizzle 2001), but whether this is true for white sturgeon is not known.

Data from trawl fishery statistics (DFO files and BC Commercial Catch Statistics) show sturgeon were taken in coastal waters, but they were not identified to species until 1996. Anecdotal evidence suggests however that most of the trawl caught fish were green sturgeon and recent data from the DFO trawl observer program (1996-2002) showed that white sturgeon occurred in 7 out of 151 138 sets; the other sturgeon caught were green sturgeon. One of the white sturgeon catches reported a biomass of 0.5 kg, suggesting this may have been a small fish. Almost all of the trawl effort was outside of the Strait of Georgia so coastal waters directly off the mouth of the Fraser River were poorly represented.

Based on concentrations of strontium in fin rays, Veinott et al. (1999) concluded that sub-adult and adult white sturgeon from the Fraser River do not regularly migrate to the sea. However, recent unpublished data (D. Lane, Malaspina College, Nanaimo, BC, pers. comm.) show that occasional adult white sturgeon have been found in small estuaries on Vancouver Island. Based on their chemical data, Veinott et al. (1999) concluded that some of the subadult white sturgeon from the Fraser River they sampled "spent their early years either in an estuarine environment or migrating to the estuary periodically". Very young white sturgeon are not tolerant of salt water (Conte et al. 1988 cited in Veinott et al. 1999).

Although the migrations of substantial numbers of adult radio-tagged white sturgeon has been documented within the lower Fraser River (Echols 1995), movement into the estuary and coastal waters would not have been detected in these studies because radiotags cannot transmit through salt water. In the Columbia River, studies using permanent tags conducted over a period of 27 y showed that a small portion of captured tagged fish (4 % or 211 tags) were taken in distant waters requiring up to 528 km of marine travel (DeVore and Grimes 1993 cited in Echols 1995).

3.1.3 Rearing habitats

*Intertidal habitat (*IH*)*: White sturgeon apparently do not use the intertidal/littoral zone of the Fraser River as habitat but they may be dependent on detrital food webs originating from marsh habitats in this zone (Northcote 1974). No white sturgeon have been caught between the river mouth and Chilliwack in the numerous beach seine surveys (total several hundred hauls) conducted by this author and colleagues over the past 20 y (summarized in Levings 2003). White sturgeon were not found in intertidal creeks and channels in the lower river in the extensive work by Levy and Northcote (1981). However small numbers of white sturgeon were caught by beach seine in the North Arm and lower reaches of the Main Arm (Fig. 2) by Northcote et al. (1978). Using the same sized beach seine 21 y later and sampling at the same locations, Richardson et al. (2000) did not catch any white sturgeon in the lower reaches but did report white sturgeon from further upriver (between river km 40-60). The latter authors used a deeper seine compared to the net used in the surveys reported by Levings (2003) (depth 7.6 m vs. 2.0 m), suggesting the white sturgeon are residing in channel as opposed to intertidal habitat.

Estuarine tidal channel habitat (ETC): as described above (Veinott et al. 1999), there is evidence that sub-adult white sturgeon move into saline estuarine channel habitats in the lower Fraser. Recent population estimates indicated that in 2000-2001 5683 white sturgeon (size 40-220 cm) were living in the estuarine channels between Steveston and Annacis Island (FRSCS 2002). Historically, the main arm of the Fraser was highly braided and shallow with multiple channels (Johnston 1921). The main arm is now a deep channel whose depth is controlled by dredging and training walls in a single main channel up to Surrey (river km 32) to accommodate deep-sea ships. Depth ranges from about 10-13 m in these reaches. Fishery data and research surveys confirm the importance of ETC habitats for adult white sturgeon. In estuarine tidal channels, gillnets caught white sturgeon as a target species, as bycatch, and in nearshore research surveys (Echols 1995; Northcote et al. 1978). White sturgeon were also killed in suction dredging the main river channel in the reaches near Steveston (Dutta 1976). Burger (1994) sampled with a small otter trawl in the estuarine reaches of the North Arm and no white sturgeon were caught in 129 trawls, but this is a very shallow channel (< 10 m) characterized by degraded water quality.

Estuarine tidal slough (ETS) *habitat*: White sturgeon have occasionally been reported from this type of habitat. Birtwell (DFO, West Vancouver Laboratory, unpublished data) reported two white sturgeon from Deas Slough (Fig. 2) (salinity 0.1-0.2 ‰) in April and June 1979.

Freshwater tidal channel habitat (FTC): Approximately 80 km of the main stem river (from Annacis Island upstream to Chilliwack) can be considered freshwater tidal habitats, except during freshet when river discharges override tidal effects. Judging from past sturgeon fisheries, First Nation fisheries, and salmon fisheries bycatch data (Echols 1995), the FTC habitat is a key habitat for adults since these fisheries targeted on this area. Recent population estimates indicated that 14 575 white sturgeon (size 40-220 cm) were living in the FTC between Annacis Island and Mission (FRSCS 2002). Evidence to date clearly shows this as primary rearing habitat for white sturgeon, with some evidence of use by juvenile fish. There is evidence of seasonal migration of white sturgeon in the FTC, as pulses of abundance in spring and autumn in three successive years were noted in gillnet catches at Albion (river km 57) (Fig. 4). As mentioned above, Northcote et al.

(1978) and Richardson et al. (2000) reported small numbers of white sturgeon caught while beach seining in these reaches of the river. Burger (1994) conducted a sampling program with a small otter trawl in the mainstem river. He reported a total of 10 white sturgeon were caught in 76 otter trawls in the mainstem Fraser near Surrey, in reaches of the river well above the salt wedge. Most of the sturgeon were caught in water depths between 7-8 m and were all < 25 cm in length.

*Freshwater tidal slough habitat (*FTS*):* Lane and Rosenau (1997) reported that juvenile (age 1+ to 15+ y) white sturgeon were more abundant in FTS habitat compared to FTC habitat. Very few adult white sturgeon were caught in FTS habitat. Their gillnet surveys of 11 mainstem and 15 slough stations over 5 years showed higher catches of juveniles in the FTS habitats, but only 3 sloughs (Hatzic, Nicomen, Big Eddy; Fig. 2) were heavily used. Within them, preferred habitats were water depths > 5 m, suggesting the importance of deeper areas such as scour holes or pits that were found in the sloughs (Fig. 5a, b). Juvenile white sturgeon migration in and out of the sloughs mostly occurred when water temperatures were between 13-15 ºC.

3.1.4 Migratory or junction habitat

We suggest that the junctions of sloughs with the mainstem river are linking habitats that allow key connections between ontogenetic phases in the white sturgeon life history. Due to the lack of data on migrations from estuarine and freshwater tidal channel habitat, it is not clear if white sturgeon perform up- and downriver movements through ETC and FTC habitat as is known for sturgeons elsewhere (e.g. shortnose sturgeon (*Acipenser brevirostrum*; Collins et al. 2000)). Lane and Rosenau (1997) showed through tagging studies that juvenile white sturgeon move seasonally, and perhaps daily, between FTS and FTC habitat. They concluded that most juvenile white sturgeon either stay in the Fraser mainstem after leaving the slough or return to their "resident" slough on a continual basis. It also appeared that the juveniles returned to the sloughs from the main stem of the river in decreasing numbers as the summer progressed. There are no detailed data on migration behaviour of white sturgeon in ETS and ETC habitat. However, we hypothesize that it is similar to that observed further up river. Numerous major sloughs have been cut off from the main stem in the lower river (e.g. Hatzic slough; Fig. 5a) by diking. In addition because the river is constrained by dikes and channelization, there is no opportunity for degradation of sloughs by channel changes and development of new sloughs as there would be off a naturally evolving and braiding river estuary (e.g. Fig. 5b; Nicomen Slough). A similar scenario is likely with excessive gravel mining in the reaches of the river upstream of FTC (Church et al. 2001).

Preliminary modelling results provide further support that the quality and access to FTS habitat is potentially critical for white sturgeon populations. We developed an age-structured density-independent model for white sturgeon that includes much of the important life history, such as a long age to maturity and spatial segregation of the ontenogenic stages (Nelson and Levings in preparation). The model incorporates spawning movement of the adults from the FTC to the FTS and age-dependent movement of the juveniles from the rearing ground of the FTS back to the FTC. The life-history parameters were estimated for white sturgeon in the Fraser River using data from Lane and Rosenau (1997). The model clearly demonstrates that habitat degradation and reduced access to FTS have a strong negative impact on white sturgeon population dynamics. In order to relate the model predictions more directly to slough cut-off, we use a range of scenarios that link slough cut-off with FTS habitat quality and access. We refer to these as sensitive, linear and robust (Fig. 6). In the sensitive scenario, as the FTS habitat shallows because of flow reduction, effects such as increased temperature, excessive fine sediment, decreases in dissolved oxygen, and other factors all combine to cause a rapid decrease in survival with increasing slough cut-off. In the linear scenario, there would be permanent loss of habitat as the slough was gradually filled or water exchange totally impaired and white sturgeon survival would decrease in direct proportion to the amount filled. In the robust scenario, white sturgeon survival would be unaffected by habitat change up to a threshold level when survival would sharply decrease. For all scenarios, the model results demonstrate that slough cut-off has a negative impact on the population dynamics that always results in extinction for less than complete cut-off (Fig. 7). This suggests that if there is impairment in the linkage between the critical FTS and FTC, regardless how slough cut-off degrades habitat quality and access, then insufficient conditions exist for population growth. Our analysis of the model also revealed that survival at the juvenile and spawning adult stages, relative to other life history transitions such as egg and larval survival, had the greatest impact on population dynamics.

3.1.5 Food supply areas

The feeding habits of juvenile white sturgeon clearly indicate the species food base is dependent on the detrital food web (Northcote et al. 1979) and hence is linked to carbon sources in the intertidal zone and floodplain land. The diet of white sturgeon is highly variable and juvenile fish are particularly opportunistic, with a wide variety of invertebrates (mysids, chironomid larvae, and other aquatic insect larvae) reported as food in FTC and FTS habitat (Northcote et al. 1979; Lane and Rosenau 1997). Subadult white sturgeon caught in ETC habitat fed on estuarine crustaceans including amphipods and crangonid shrimp. Adult fish are mainly piscivorous. Eulachons, salmon, and cyprinids have all been reported as stomach contents in larger fish from the lower Fraser (Lane and Rosenau 1997).

3.1.6 Substrate

Experimental data from several species of sturgeon showed that juvenile fish prefer non-vegetated and level sand bottoms (Sbikin and Bibikov 1988). Specific information on substrate preference for white sturgeon in the Fraser River estuary is not available. However because sand is the dominant substrate in the ETC and

FTC habitat (Northcote et al. 1976), it is likely the species is adapted to this sediment type.

4. STATUS OF HABITAT MAPPING, PAST IMPACTS, CURRENT THREATS

4.1 Habitat mapping

Fish habitat managers working in the lower Fraser River and estuary use the Fraser River Estuary Management Program (FREMP) habitat classification scheme for fish habitat management. This scheme was developed for salmon habitat in the 1980s and is used up to about river km 38, the upstream boundary of the FREMP area. The scheme does not recognize the connectivity aspects of habitat and the protocols in use are biased toward intertidal habitat, with only five habitat types recognized (riparian trees, riparian grasses and shrubs, intertidal marsh, mudflat, and sandflat) because of their importance for juvenile salmonid rearing. Currently there is an active program, sponsored by FREMP partners, to upgrade the habitat maps but the original scheme is being used. There are no current plans to map subtidal habitat (ETC, ETS, FTC, FTS) (FREMP, pers. comm.).

4.2 Assessment of past impacts

As has occurred in many estuaries around the world, the Fraser River estuary has been changed by human activities. In the Fraser estuary, white sturgeon habitat such as ETC, FTS, and FTC have not been systematically mapped but clearly there has been significant habitat loss. White sturgeon populations are currently depleted in the lower Fraser and their estuarine habitats may now be under utilized. However there are no substantial data to compare changes in their habitats through time. Human activities have decreased the area of most habitat types discussed in this paper. Major areas of intertidal and shallow subtidal habitats have been lost owing to diking and urbanization. Several major sloughs (e.g. Deas, Gunderson Slough, Hatzic Slough (Fig. 2) (ETS and FTS)) have been severely modified, usually by cutting off flow at their upstream ends, diking for flood control, or complete removal to develop farm land (e.g. Sumas Lake) (Levings 2003). In 1919 (Johnston 1921), the maximum landward penetration of the salt wedge in deeper channels from the mouth was about 5 km, but now, in the dredged channel, the wedge extends 20 km further upriver (Ages and Woolard 1994). In this instance, FTC has been replaced by ETC habitat

Therefore we cannot predict if the remaining habitat is sufficient to support populations at historical or current levels because the existing habitat mapping schemes have probably not measured the pertinent biophysical attributes (Table 1). All historical vegetation mapping has focused on marsh and riparian habitat. Moore (1990) considered that about 70 % of this habitat type has been lost owing to urbanization and industrial development. Healey and Richardson (1996) used a similar figure to complete a carbon budget for the estuary, with an explicit mention of white sturgeon habitat. If food is a limiting factor for white sturgeon, it is possible that loss of wetlands has had an effect on survival. However because data are lacking on this topic, it is not clear if the amount of food -producing habitat has fallen below a threshold level.

It is clear that physical modification of white sturgeon ETC and FTC habitat has occurred in the past as the lower river and estuary have been straightened and modified for navigational purposes by engineering structures and dredging - essentially, the river's geometry has been modified (Hales 2002). Dutta (1976) documented white sturgeon killed during suction dredging in ETC and as the current guidelines do not provide for explicit protection of white sturgeon it is likely such mortality is still occurring.

About 10.6 ha of sturgeon habitat, especially FTC, has been converted to intertidal marsh in restoration or compensation projects (Fig. 8; FREMP 2001). There may have been some indirect benefit to sturgeon because of increments in detrital production from the restored or created marshes but their ability to produce detritus in the long term has not been established (Levings and Nishimura 1997).

4.3 Assessment of current threats

Dredging and channelization in the tidal estuary has affected depth (D), width (W), and length (L) of all four potential critical habitats and maintenance dredging is therefore an ongoing threat. While there are data available on the contemporary dimensions of ETC, FTS, and FTC habitats and connectional data between these habitats (available on Canadian Hydrographic Service charts), there has been no systematic investigation of the changes in D, W, or L in these habitats over time. Excessive gravel mining in the reaches immediately upstream of the tidal estuary may be affecting the competency of the river to carry sediment (Church et al. 2001), thereby changing equilibrium conditions for all habitats downstream. Log storage and loss of bark in water can result in low dissolved oxygen (DO) levels, especially in cutoff FTS and ETS habitats. Blockage of ETS and FTS by urban and industrial development, including flood controls, has both removed habitat and in some cases created areas with poor water exchange and low DO. ETS habitats have been surveyed (I. Birtwell, DFO, West Vancouver Laboratory, pers. comm.) and few white sturgeon were recorded. In 1993 and 1994, several dozen dead white sturgeon were found in the lower Fraser but the causes of their deaths has never been determined; there is speculation that contaminants were implicated (Glavin 1994).

A summary of the criteria or methods currently in use or proposed to assess fishy habitat Fraser River and estuary is given in Table 1. Methods used at present focus on intertidal or supralittoral criteria and may not be directly applicable to white sturgeon. They may have some relevance if they consider food supply areas since juvenile white sturgeon are dependent on the detrital food web, which has its bases in riparian vegetation. However if an action plan to preserve existing habitat or restore lost potentially critical habitat for this species is required, we recommend development and testing of methods that focus on the morphology of channels and sloughs and the sediment of the lower river.

5. COMPARISONS, CONCLUSIONS AND RECOMMENDED RESEARCH

There is a lack of peer reviewed publications on the habitat ecology of white sturgeon living in the tidal estuary of the Fraser River. Data are particularly scarce in comparison to the Atlantic sturgeon (*Acipenser oxyrhincus),* the other sturgeon species in Canada with an estuarine life history component (e.g. St. Lawrence River: (Caron et al. 2002)), and other white sturgeon estuarine populations on the west coast of North America (e.g. Columbia River: McCabe and Tracey 1994; Sacramento: Chapman et al. 1996). If recovery plans are developed for the white sturgeon population in the Fraser River estuary, further research is required to determine if the habitat is sufficient and to investigate if current habitat management practices will enable maintenance of potentially critical habitat. Since habitat management in the Fraser estuary tends to be driven by juvenile salmon requirements of shallow intertidal areas, the relationship between those habitats and white sturgeon needs should be explored.

Table 2 lists six important aspects of ecological research that would improve our knowledge of potentially critical habitat for white sturgeon in the tidal estuary. Comments are given on each: home range estimates, habitat links and migration corridors (especially data on requirements of the species to access brackish water), and methods to investigate how white sturgeon access a variety of habitats in different life stages, substrate requirements, water quality, and development of methods to investigate aspects of habitat integrity (e.g. importance of upstream in within-estuary sediment sources to maintain white sturgeon habitat). A pilot scale mapping project using existing habitat data from Canadian Hydrographic Service charts (e.g. dimensions of channels and sloughs) is another priority that could be conducted at the same time that biological investigations are underway.

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Table 1. Current and proposed methods and criteria used for identifying potentially critical habitat for white sturgeon in the Fraser River estuary.

Criteria	In use?	GIS-Map scale	Utility-Relevance	Reference
Wetland loss	Yes (salmonid habitat only)	1: 50 K	some	Moore, 1990
Littoral production indices	Yes (salmonid habitat only)	1: 5 K	some	FREMP, 2002
Carbon loss	no	1: 1 M	some	Healey & Richardson 1996
Sediment budget-geomorphology	Under development	1: 5 K	good	Church et al, 2001
Connectivity indices	Proposed	1: 5 K	good	This paper

Table 2. Suggestions for research topics and mapping that could improve prospects for determining potential critical habitat for white sturgeon in the tidal estuary of the Fraser River.

Topic	Comments/Questions
Home range	10s of km in life span, but likely shorter distances for specific life history stages
Habitat links/connectivity	Dependent on access to and from potential critical habitat; need to confirm that access to brackish water is necessary for survival
Biological linkages	Larvae-juvenile-adults require succession of benthic habitats; larvae-juveniles part of detrital food web but adults may be piscivores; is there density-dependence mediated through food supplies?
Substrate	Dependent on watershed conditions and sediment supply
Water quality	Some bioaccumulation of organic contaminants has been documented
habitat integrity	Methods needed to relate hydraulic connectivity and channel-slough dynamics to ecological parameters
Scale of habitat mapping required	1 : 5000
Recommendation for potential critical habitat mapping?	Yes, using Canadian Hydrographic Service data

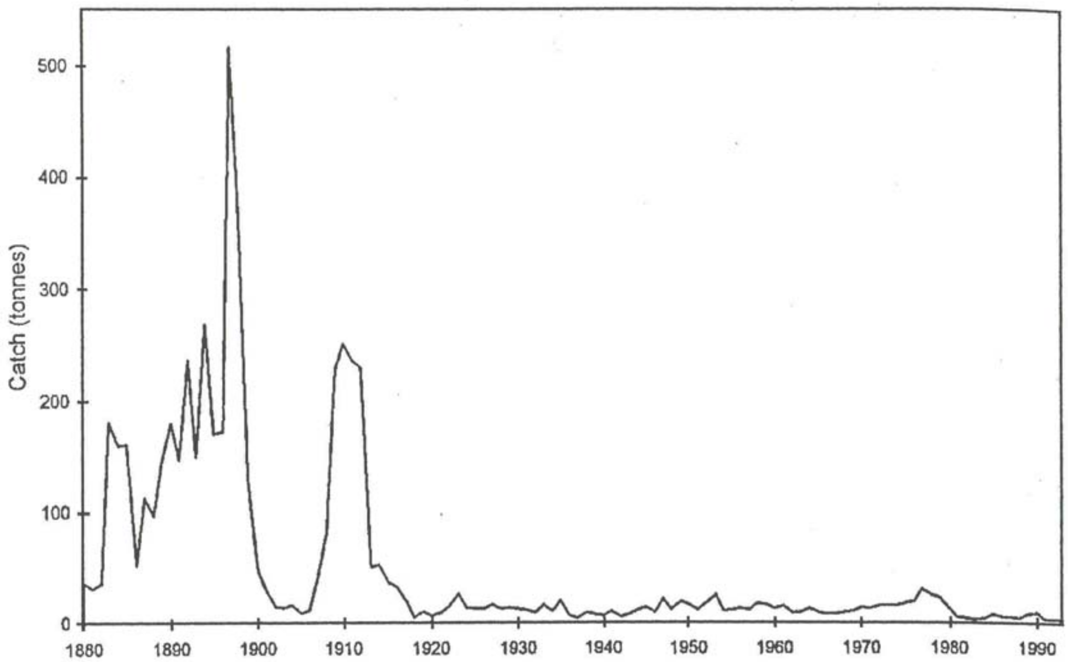

Figure1. Estimated commercial gillnet harvest (tonnes) of sturgeon in the Fraser River, 1880-1993 (from Echols, 1995).

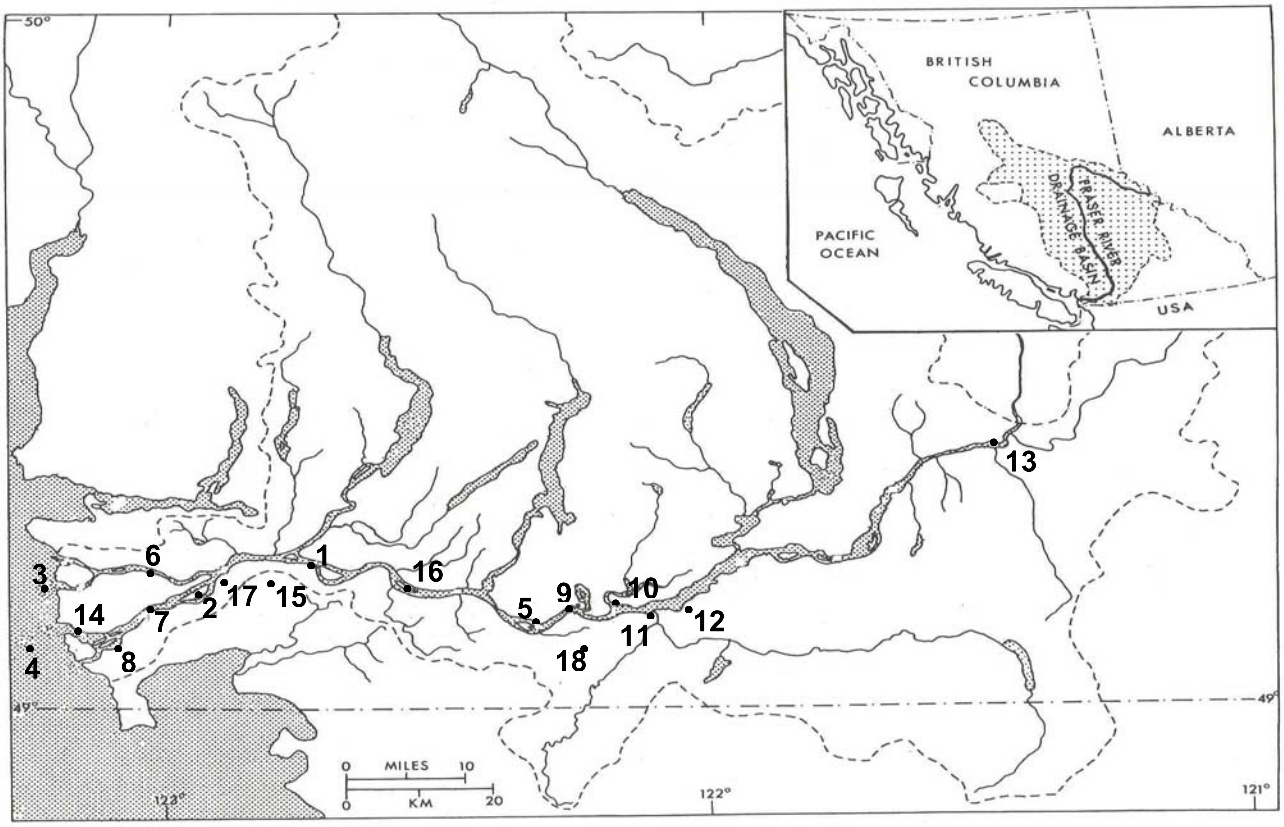

Figure 2. Map of the lower Fraser River and approximate location of places named in the text. 1- Fraser River; 2- Annacis Island; 3- Sturgeon Bank; 4 - Strait of Georgia; 5 – Mission; 6 - North Arm; 7 - Main Arm; 8 - Deas Slough; 9 - Hatzic Slough; 10 - Nicomen Slough; 11 - Big Eddy Slough; 12 – Chilliwack; 13 – Hope; 14 – Steveston; 15 – Surrey; 16 – Albion; 17 Gunderson Slough;18 Sumas Lake (now drained).

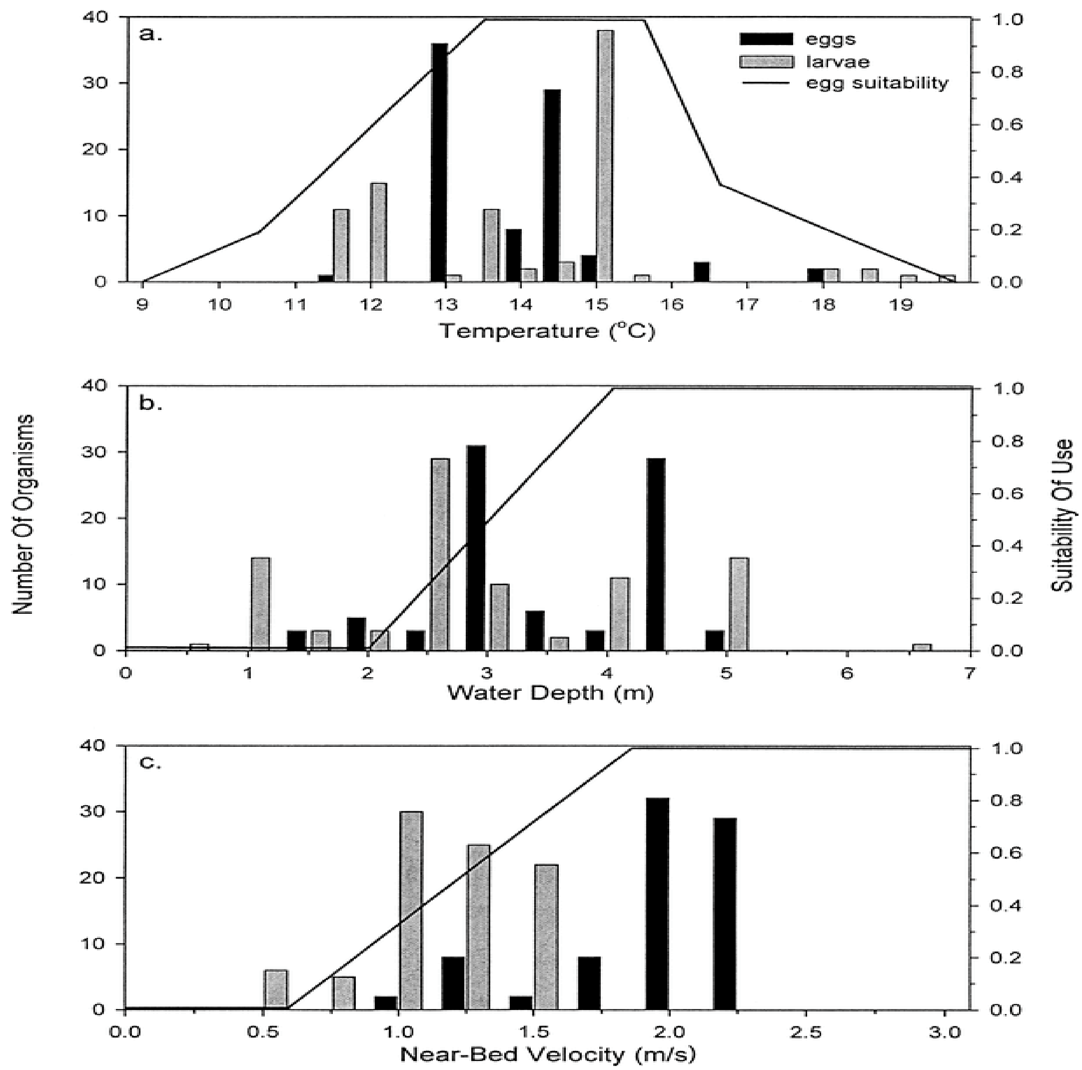

Figure 3. Water temperature (a), depth (b) and velocity (c) at sites where white sturgeon eggs, embryos and larvae were collected in three freshwater tidal sloughs in the lower Fraser River. Curves for each plot indicate the published suitability-of-use conditions for spawning in Columbia River where 0 is most unsuitable and 1 is most suitable (from Perrin et al. 2003).

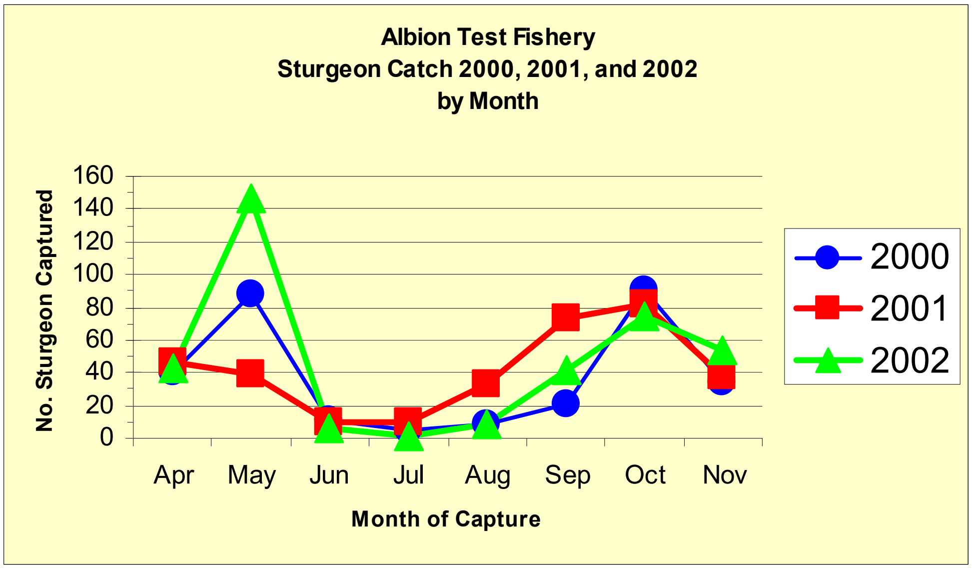

Figure 4. Seasonal fluctuations in DFO test fishery gillnet catches of white sturgeon at Albion in 2000, 2001, and 2002. Data interpretation courtesy of Troy Nelson, Fraser River Sturgeon Conservation Society.

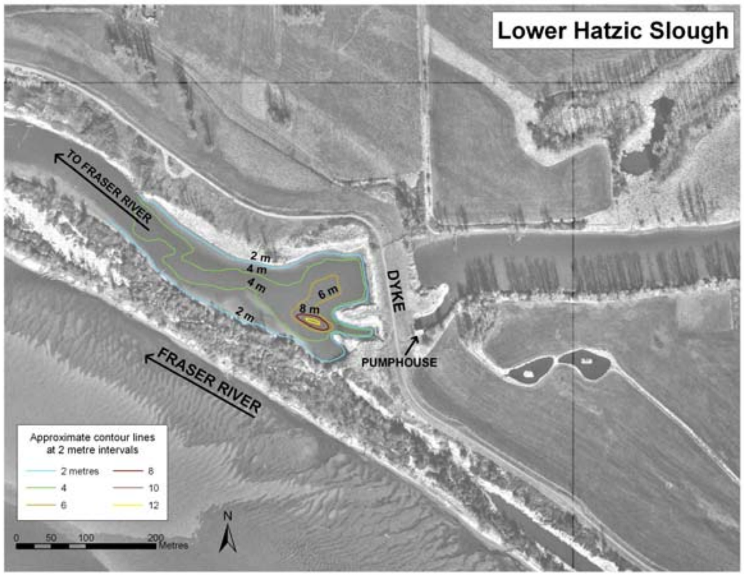

Figure 5a. Orthophoto (2001) of the mouth of Hatzic Slough, lower Fraser River, showing dike constructed for flood control. Reproduced with permission of D. Ham, Department of Geography, University of BC. Depth contours (m) from Lane and Rosenau (1997).

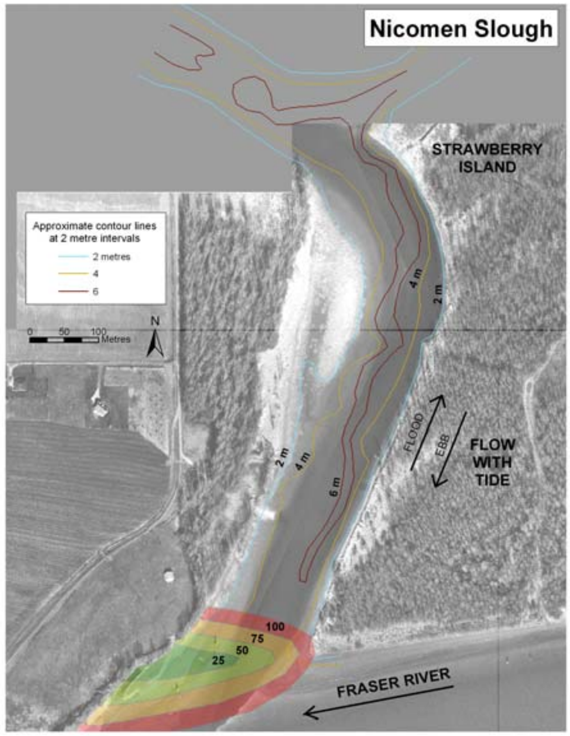

Figure 5b. Orthophoto (2001) of the mouth of Nicomen Slough, lower Fraser River and hypothetical blockages between the slough and the main river. Baseline photo reproduced with permission of D. Ham, Department of Geography, University of BC. Depth contours (m) from Lane and Rosenau (1997).

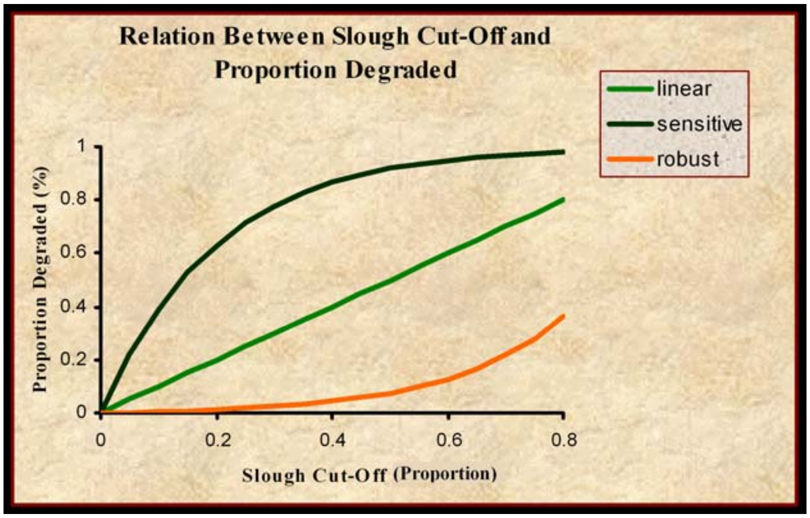

Figure 6. Relation between proportion of slough cut-off from main river and proportion degraded under linear, sensitive, and robust scenarios in the simulation model used to forecast habitat effects on white sturgeon populations in the tidal Fraser River estuary (from Nelson and Levings, in preparation).

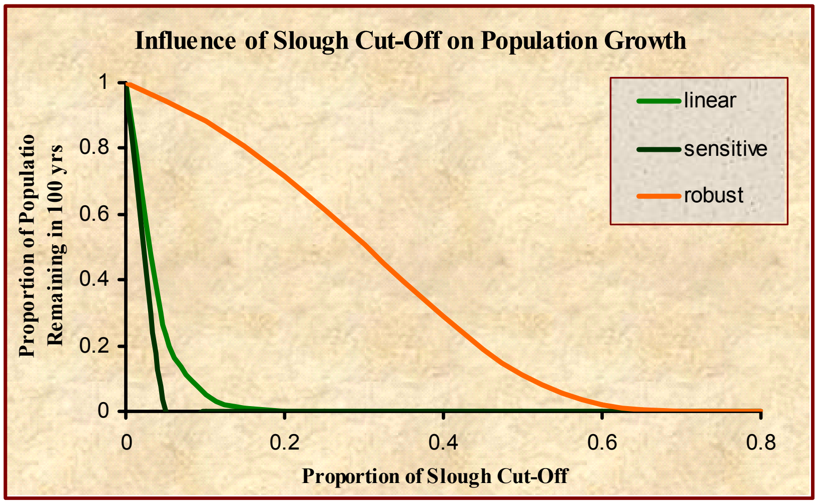

Figure 7. Modelled relationship showing the effect of increasing proportions of slough cut off on white sturgeon. Effects are shown as proportion of population remaining in 100 y. (from Nelson and Levings, in preparation).

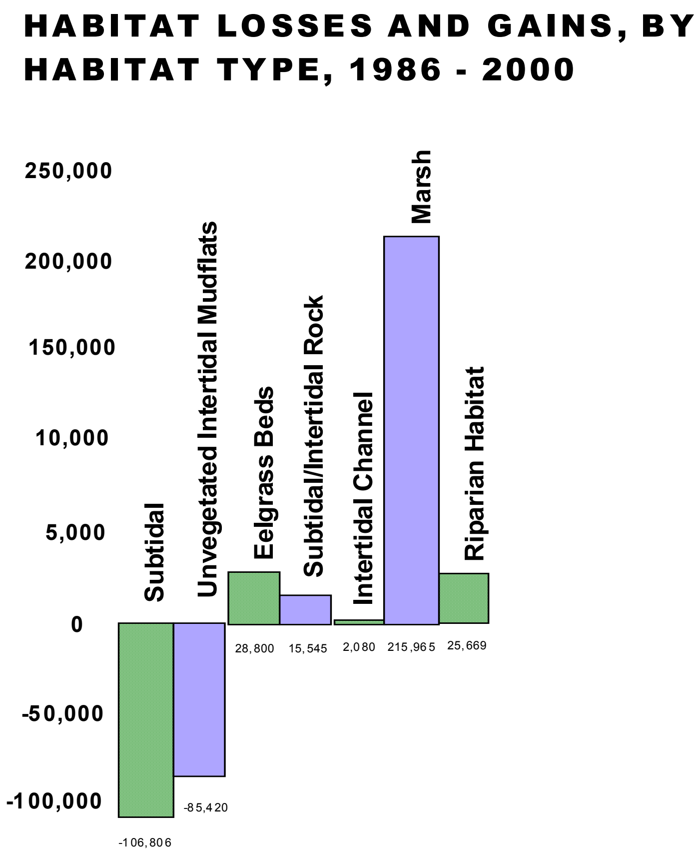

Figure 8. Gains and losses of various habitat types in the lower Fraser River, 1986-2000. From Fraser River Estuary Management Program, 2001.