FRASER RIVER STURGEON

November 1995

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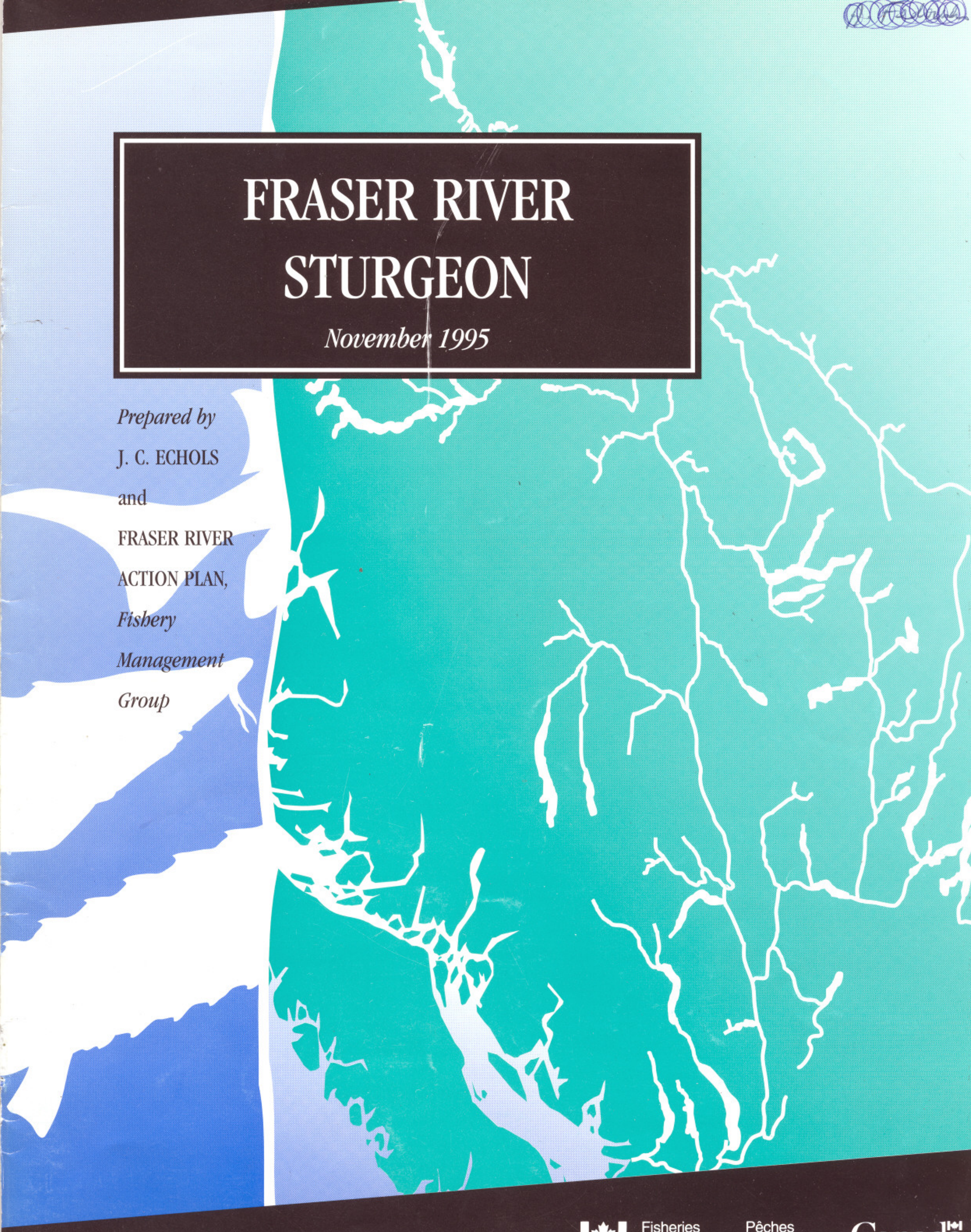

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REVIEW OF FRASER RIVER WHITE STURGEON

(Acipenser transmontanus)

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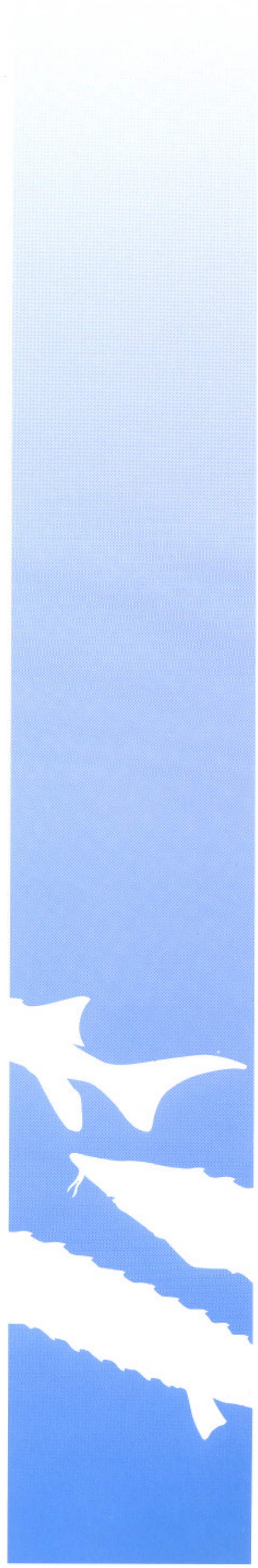

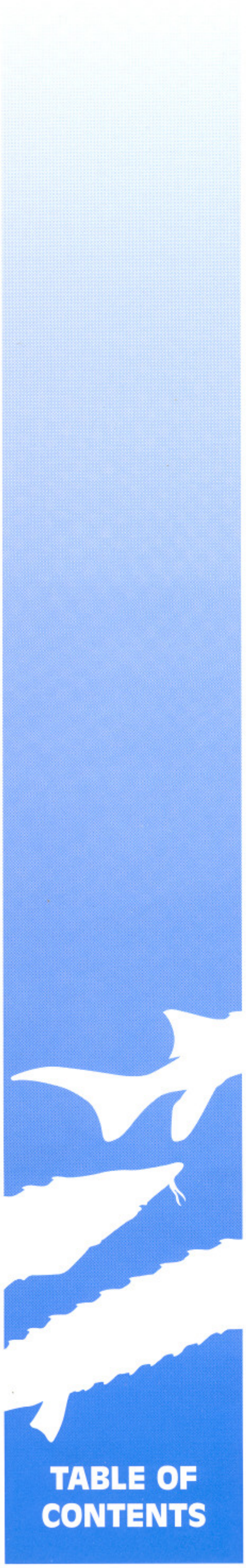

CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

SUMMARY

1. White sturgeon are the largest freshwater fish in Canada. They were declared "vulnerable" by the Committee on the Status of Endangered Wildlife in Canada. In addition, their provincial classification was changed from blue to red to indicate an endangered status.

2. Very little information is available on the Fraser River white sturgeon. This report reviews existing biological and fisheries information as it applies to this population.

3. Fraser River white sturgeon became commercially important during the late 1800s and early 1900s, with annual harvests exceeding 200 tonnes in some years. Subsequently, commercial catches declined drastically to below 20 tonnes per year.

4. The federal Department of Fisheries and Oceans manages all commercial and aboriginal fisheries in all B.C. waters, as well as recreational fisheries in tidal waters; the provincial Ministry of Environment, Lands and Parks (MELP) manages non-tidal (freshwater) recreational fisheries. Currently, both agencies are attempting to cooperatively manage the Fraser River sturgeon. At present, all commercial and recreational fisheries in the Fraser River must release all caught sturgeon in accordance with the 1994 retention ban; while aboriginal fisheries in the Fraser have agreed to a voluntary release of caught sturgeon.

5. Harvest data on the Fraser white sturgeon captured in each of the aboriginal, commercial and recreational fisheries, vary in their historical recording, resolution and data-type. The aboriginal data, available only since 1983, consist of catch and effort statistics, but lack accuracy regarding the numbers of fish killed. The more extensive commercial records, available since 1880, provide only catch by weight, and do not differentiate between green and white sturgeon. Recreational harvest data are detailed, but only for recent years. Poaching is considered a serious problem but no estimates of its extent are available.

6. The only facility in British Columbia that uses the Fraser white sturgeon broodstock for aquaculture purposes is located at Malaspina University College in Nanaimo, B.C. Aquaculture studies conducted in the U.S. are reviewed.

7. The few available production estimates for white sturgeon show a wide range of sustainable exploitation rates, depending on modelling assumptions.

8. Currently, the provincial agency, MELP, is conducting tagging studies in the middle and upper Fraser River to complement the completed study in the lower Fraser. A list of possible research and management studies is included for discussion purposes.

SUMMARY

1.0 OVERVIEW

The white sturgeon (*Acipenser transmontanus*) is the largest North American sturgeon species and probably the largest freshwater fish in Canada, with a maximum reported length of 6.1 m (Scott and Crossman 1973). Specimens from the Fraser River historically weighed over 600 kg (Daily Columbia, New Westminster, Aug. 14, 1897). The flesh of white sturgeon is highly esteemed as food, and the eggs, sometimes as many as 90 kg in a single female, are readily prepared and marketed as caviar (Scott and Crossman 1973).

In British Columbia, the largest known population of white sturgeon that accesses the Pacific Ocean is found in the Fraser River. In 1991, white sturgeon were declared "vulnerable" by the federal Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Campbell 1991), where "vulnerable" stocks were defined as those subject to

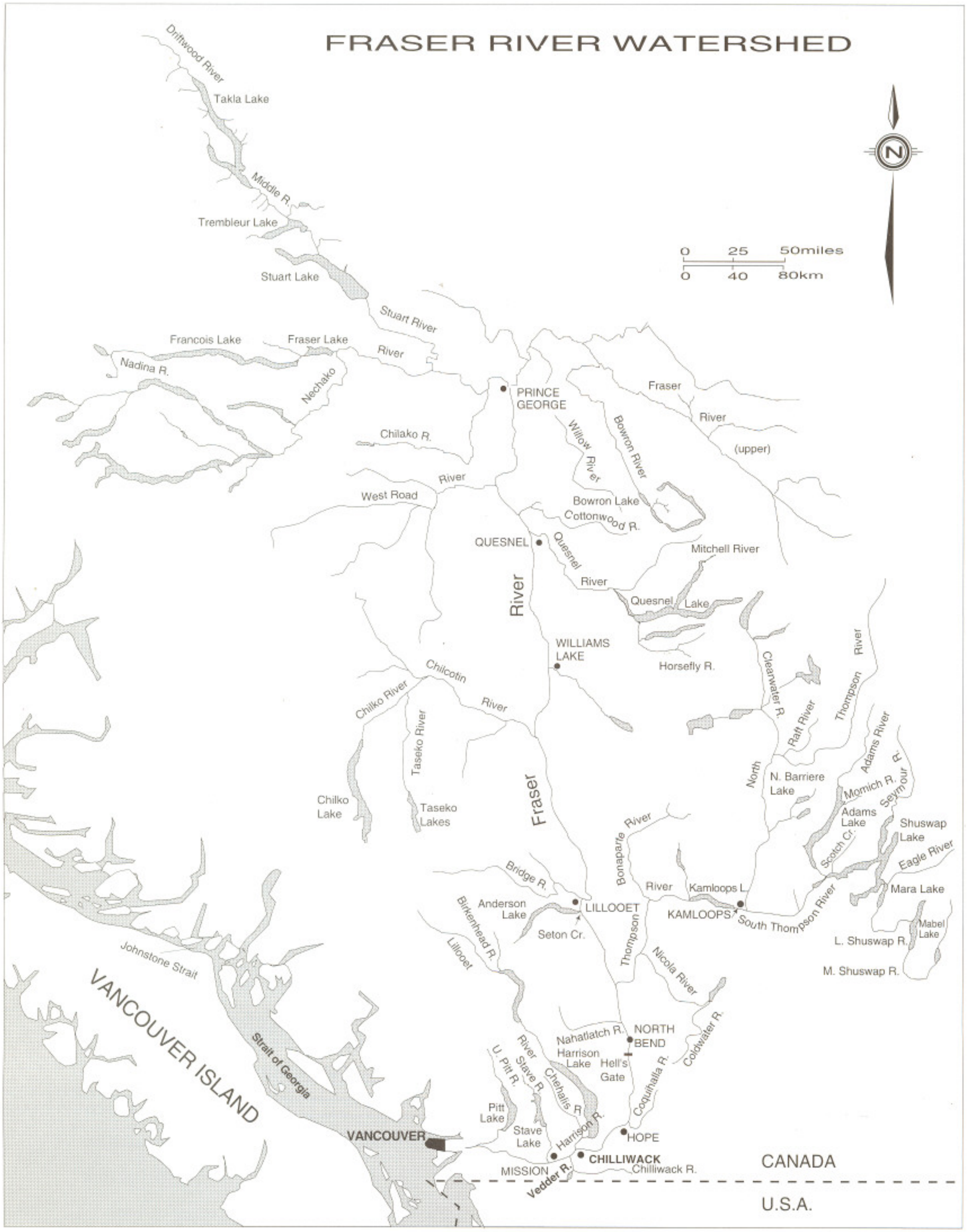

Fig.1. Fraser River watershed.

change in response to fishing pressure and habitat disturbance. Recently, the B.C. provincial classification of the Fraser River white sturgeon was changed from blue to red (2 to 3 on scale of 3) to indicate an endangered status (J. Ptolemy, MELP, pers. comm.).

While this report deals with the Fraser River white sturgeon, another smaller species - the green sturgeon (*A. medirostris*), is also found in the lower Fraser River. The green sturgeon were classified as rare by the COSEWIC, although even less is known about this species, compared to the white sturgeon. The two species are difficult to distinguish readily, and currently, provincial and federal fishing regulations and catch records do not differentiate between these two species. As yet, there have been no field studies or policy initiatives focused on the green sturgeon in B.C. Appendix 1 provides information on the morphology and distribution of this species.

Prior to 1985, data collection on the Fraser River white sturgeon was limited, but has increased since that time. Currently, the provincial Ministry of Environment, Lands and Parks (MELP) is funding biological studies on the Fraser River white sturgeon, with the study area extending from Yale (above Hope) to the upper reaches near Prince George (Fig. 1). In an effort to strengthen the research and management initiatives on Fraser River white sturgeon, MELP and the federal Department of Fisheries and Oceans (DFO) have agreed to work jointly on improving the health of white sturgeon stocks.

Given the very limited information available on Fraser River white sturgeon, the purpose of this report is to review and summarize existing information, and stimulate development of sturgeon management initiatives within DFO. While much of the scientific information included here is based on white sturgeon populations in the Columbia and Sacramento rivers of the western United States, this information remains useful in addressing the biological and management issues of the Fraser River white sturgeon population.

1.1 STURGEON DESCRIPTION

The sturgeons evolved morphologically during the late Palaeozoic Era, 290 million years ago (Alexander 1981). Sturgeon skeletons are primitive, cartilaginous structures with small amounts of bone in the pelvic girdle, skull membranes and jaw. As in sharks, the pelvic girdle in sturgeon is inflexible and cannot aid in locomotion. Sturgeon are heavy subcylindrical fish with extended hard snouts, and a ventral protrusible mouth preceded by 4 barbels (Fig. 2, Scott and Crossman 1973). These fish have no scales, but rather large bony

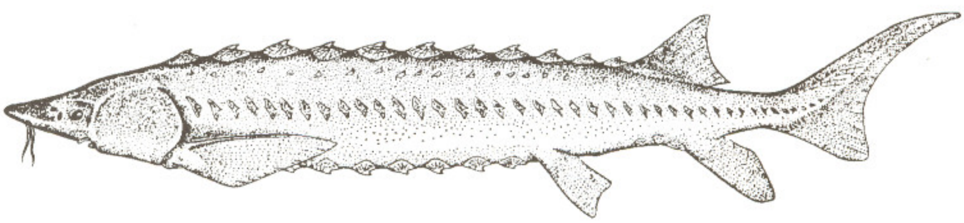

Fig. 2: White sturgeon *(Acipenser transmontanus)* (from Scott and Crossman, 1973).

plates (scutes) arranged in 5 rows (1 dorsal, 2 lateral, and 2 lateroventral), as well as small hooks (spiracles) attached to the skin. Some authors hypothesized that the tough sturgeon skin serves partly to reduce predation (Cech et al. 1984). While the evolutionary classification of sturgeons based upon physical characteristics is still debated, evidence from Tamai et al. (1994) suggests that sturgeons are not well advanced and possess similar biochemical traits in the brain as the bichir, an African fish capable of respirating air.

Scott and Crossman (1973) provide the most comprehensive description of white sturgeon and list the following morphological attributes:

MORPHOLOGICAL CHARACTERISTICS OF WHITE STURGEON

1.	Body Cross Section	Less pentagonal and more rounded than in other sturgeon species.
2.	Body	Greatest depth about 14% of total length.
3.	Head	Large and broad, about 25% of total body length.
4.	Mouth	Protrusible.
5.	Eyes and Snout	Eyes small; snout short; 4 barbels anterior to mouth and slightly closer to tip of snout than to mouth.
6.	Gill Rakers	Long, 34-36 on first arch.
7.	Dorsal Fin	One dorsal fin placed far back over anal fin, 44-48 rays.
8.	Caudal Fin	Upper lobe markedly longer than lower lobe.
9.	Skin	Scaleless, except for 5 rows of bony plates (scutes) running laterally from head to tail. Dorsal plates number 11-14; lateral 38-48; and ventral 9-12. No plates between dorsal and caudal fins, or between anal and caudal fins. Two rows of 4-8 plates between pelvic and anal fins.
10.	Lateral Line	None.
11.	Body Colour	Light grey, pale olive or light brown on dorsal surface; ventral surface light grey to white.
12.	Body Size	Maximum reported length of 6.1 m.

Burggren (1978) observed that gill structures in white sturgeon were ideally adapted for bottom dwelling and feeding. Sturgeon also possess a small swim bladder which assists them in remaining close to the substrate. Burggren and Randall (1978) studied the respiration in white sturgeon, and found that these fish compensated for low dissolved oxygen levels by increasing volume of gill ventilation without changing ventilation frequency. As a result, oxygen utilization did not decrease significantly. An interesting finding in their study was that white sturgeon were apparently able to decrease their energy expenditure (metabolism) during periods of low dissolved oxygen levels.

1.2 HISTORICAL BACKGROUND

Archaeological findings (carbon-dated to 3,000 years ago) in California provided the first known evidence of white sturgeon remains in North America (Gobalet 1990). While no documented archaeological evidence exists for the Fraser Basin at this time, white sturgeon have been important in the food and ceremonies of Fraser River aboriginal peoples for many centuries. Glavin (1994) discussed this importance, gleaned from interviews with aboriginal peoples from the lower Fraser area.

Historically, the bulk of Canadian catch of white sturgeon came from the Fraser River where it was taken in nets set for salmon (*Oncorhynchus spp.*) (Scott and Crossman 1973). Fraser River white sturgeon became commercially important during the late 1800s and early 1900s. Harvest increased after 1880 by an average of 27 tonnes per year, and peaked at 517 tonnes in 1897 (Fig. 3). Sturgeon weighing up to 184 kg were a daily occurrence in the Fraser River catches at this time. During this period of intensive harvesting, sturgeon were taken primarily for their roe (caviar) and swim bladder linings (isinglass); the latter were used in the production of commercial glues and for beer/ale clarification. Catches fell

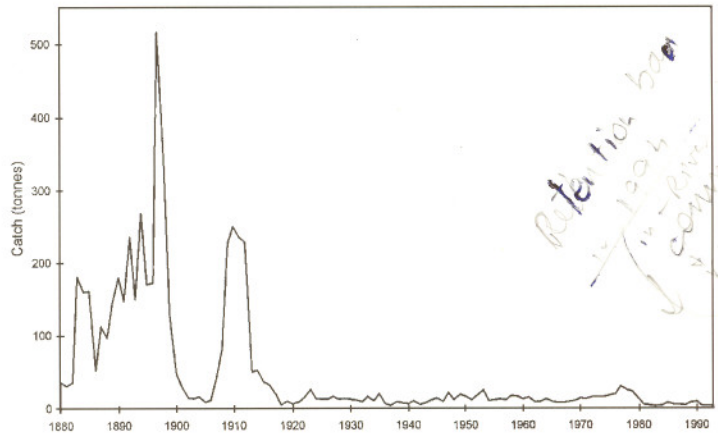

Fig. 3. Estimated commercial gillnet harvest (tonnes) of sturgeon in the Fraser River, 1880-1993 (data from B.C. Commercial Catch Statistics; includes green and white sturgeon catches; 1 tonne=1,000 kg.).

drastically in the early 1900s, and by 1905 the annual sturgeon harvest averaged only 20 tonnes. This was followed by a short period of recovery, but since 1917, the annual commercial harvest of Fraser sturgeon rarely exceeded 15 tonnes (Fig. 3).

The above pattern of exploitation was not uncommon with sturgeon species (Semakula and Larkin 1968). Commercial white sturgeon fisheries in the Columbia and Sacramento rivers (Hanson et al. 1992), and beluga sturgeon (*Huso huso*) fisheries in the Volga River (Raspopov 1993) have yielded abundant catches of large specimens that were typical for the first 10 years of each fishery's inception. These high catches were followed immediately by dramatic declines in harvest and average body size. Such "fishing down" of older age groups is not necessarily limited to modern fisheries. Based on archaeological data from Europe, it was hypothesized that during the Middle Ages, a number of sturgeon species (beluga - *H. huso,* sterlet - *A. ruthenis,* Russian - *A. gueldenstaedti,* and stellate - *A. stellatus*) apparently had been bigger and had lived longer than those sturgeon observed prior to the Industrial Age at the end of the 1800s (Tsepkin and Sokolov (1971) in Birstein (1993)).

Although many sturgeon stocks are considered endangered or threatened (Birstein 1993), they often continue to exist at low levels of abundance for extended periods of time. The most historically extensive data for the West Coast sturgeon stocks consist of commercial landing statistics. These data, however, were generally collected many decades after the inception of the commercial fisheries (see Parks 1978). In addition, commercial catch statistics for British Columbia do not discriminate between green sturgeon and white sturgeon, thus making interpretation of existing harvest data difficult. These factors, coupled with widespread poaching on sturgeon over many years, have resulted in catch underestimation. The Fraser River sturgeon data are no exception; the documented history of white sturgeon exploitation in this system is a sparse one, and even anecdotal reports are limited. As well, extensive time lags between human/environmental disturbances and stock response have magnified the uncertainties regarding cause and effect relationships.

2.0 LIFE HISTORY AND BIOLOGY

2.1 ADULT DISTRIBUTION AND MIGRATION

White sturgeon are restricted to the Pacific shores of North America from the Aleutian Islands of Alaska to Monterey, California (Scott and Crossman 1973). Those authors noted that in western Canada, white sturgeon are known to occur in both the lower and upper Fraser reaches (Harrison, Lower Pitt and Stellako rivers, Fraser and Stuart lakes), as well as in northern B.C. (Taku River), interior B.C. (Kootenay Lake and River, Columbia River above Revelstoke), and on Vancouver Island.

The migration and distribution patterns of white sturgeon in marine and fresh waters are as yet uncertain. Scott and Crossman (1973) observed data (mainly from Carl et al. 1967) which suggested that white sturgeon are anadromous in most large rivers but landlocked in the upper Columbia River. McEnroe and Cech (1985) classified white sturgeon as semi-anadromous; that is, fish that spend most of their time in marine waters close to shore, then move into fresh water to spawn. Echols (MS 1995) used the term amphidromous to describe white sturgeon as subject to marine wandering but with spawning taking place in fresh water. However, Lane (1991) found no evidence that white sturgeon in Fraser River move to saline waters. Recently, this has changed. Eleven large mature white sturgeon were confirmed in several rivers in the Barkley Sound/Alberni Inlet area on the West Coast of Vancouver Island (D. Lane, Malaspina University College, pers. comm.). Given their coastwise distribution, this species probably also inhabits other B.C. coastal drainages.

The distribution of white sturgeon within the Fraser system is poorly known. These fish are found in the Nechako River, a major tributary to the Fraser, and access the Fraser mainstem at least as far upstream as Prince George (Fig. 1). Given the apparent diversity of sturgeon habitat and the absence of any impassable obstructions in the Fraser watershed, white sturgeon can probably access large Fraser River tributaries.

In the lower Fraser, adult white sturgeon appear to be more abundant during spring, summer and fall months, compared to winter months. Smaller white sturgeon (~50-100 cm in fork-length) were captured in prawn traps in the Fraser estuary where salinity approaches that of marine waters (M. Joyce, DFO, pers. comm.). Currently, the provincial agency, MELP, is conducting tagging studies on this species in the middle and upper Fraser reaches.

To date, two radio-tagging projects have been conducted on white sturgeon in the Fraser system. Dixon (1986) radiotagged three large specimens captured in the Nechako River (Fig. 1). During the 111 days of tracking from spring to summer of 1980, the total movement of these fish within the same 2-3 km river segment ranged from 8 km to 33 km, depending on individual fish. These movements were possibly related to food availability and spawning activity.

In a second, more recent study, Envirowest Consultants Ltd. (ECL 1992) radiotagged 18 white sturgeon between April 1989 and December 1991, and conducted radio-telemetry surveys to locate the tags. Tags were located between 1989 and 1992 on 185 separate occasions in the lower Fraser between Albion and Hope. Preliminary analysis of the data indicated that minimum movements ranged from 0 km to 70 km. Minimum movements are stressed here because of Bajkov's (1951) reasoning that a fish detected 20 km from the tagging location one year later, may have travelled only those 20 km or may have undergone an extensive migration prior to being detected at that site.

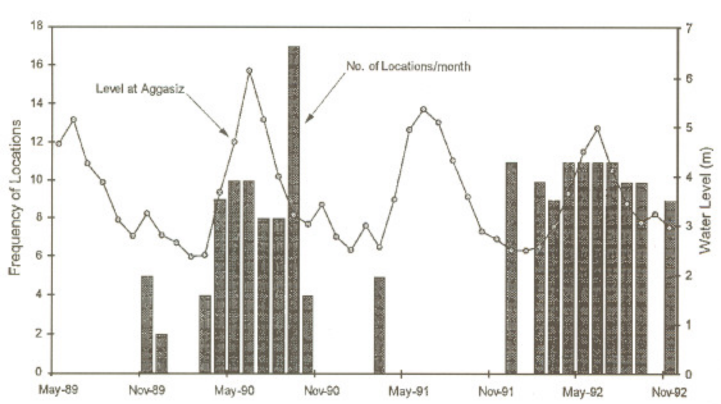

Fig. 4. Numbers of white sturgeon located in the Lower Fraser River by month from the first to the last location date (Nov. 22, 1989 to Nov. 26, 1992) (data from ECL, 1992), and mean monthly water levels (depth) in meters at Aggasiz, between Mission and Hope (data from HYDAT).

In the above study by ECL (1992), considerable time intervals of up to several months, were observed between successive detections. It is known that changes in water depth, whether seasonal or resulting from habitat selection by fish, may affect radio-reception. For example, Anders et al. (1993) observed that radio-reception was reduced significantly at higher river levels, while Haynes et al. (1978) noted that reception quality declined in the winter, presumably due to movements of sturgeon into deeper waters during their inactive periods. Figure 4 shows tag location frequencies obtained from aerial surveys, and water levels in Fraser River at Agassiz, an area within the ECL (1992) sampling zone. The long intervals between locating individual fish, despite ongoing sampling, may be attributed to one or more of the following:

1. Sturgeon moved into areas within the range of receiver detection, but were undetectable due to the distance between the transmitter and the water surface, as measured along the detection pathway from the survey plane.
2. Sturgeon moved upstream of the study area, and out of the receiver range.
3. Sturgeon moved downstream of the study area into marine waters, and out of the receiver range.

Migration studies on white sturgeon have also been conducted in other river systems. In the Columbia River, tagging studies conducted over a period of 27 years showed that a small portion of recaptured tags (4% or 211 tags) were taken in distant waters requiring up to 528 km of marine travel (DeVore and Grimes 1993). The same study showed that the general pattern of movement by white sturgeon was upstream in the fall, sedentary (not migrating) in the winter, and downstream in the summer. Haynes et al. (1978) studied the seasonal movements of radio-tagged white sturgeon in the mid-Columbia River, and observed different migration patterns for different sized fish.

2.2 ADULT STAGE

Information on life history of adult white sturgeon is very limited. Individuals of this long-lived species may reach over 100 years of age (Scott and Crossman 1973). Those authors also noted that white sturgeon captured incidentally during lower Fraser salmon fisheries generally varied in length from 0.2 m to 2.3 m, with much larger specimens weighing over 600 kg encountered. (Adult sizes are further discussed in the section on Growth, Feeding and Nutrition).

Scott and Crossman (1973) noted that sexual maturity in white sturgeon is attained at extremely variable ages, and these differ for the sexes; first spawning in Fraser River white sturgeon, estimated from growth patterns, probably takes place at age 11-22 years for males, and 26-34 years for females. For the Lower Columbia white sturgeon, the age of sexual maturity was given as 12 years for males and 15-20 years for females (Galbreath 1985). Adults survive spawning and return to spawn more than once, but only after increasing numbers of years; in younger females the interval is 4 years, and 9-11 years in older females (Scott and Crossman 1973). Nothing is known about the spawning intervals in males.

Spawning migrations of white sturgeon are not well understood. Scott and Crossman (1973) observed that mature adults of this anadromous sturgeon generally move into large rivers in the early spring, but some adults may enter freshwater in the fall and winter. Those authors also noted that the spawning period is usually May and June, but could be later for distant migrants. White sturgeon prefer to spawn in areas of high water velocity (Hanson et al. 1992), over rocky substrate and at water temperatures of 9-17°C (Scott and Crossman 1973). Spawning sites of white sturgeon in the Fraser River are not known for certain. However, these fish likely spawn below Hell's Gate (Fig. 1) in the Fraser Canyon (S. McAdam, MELP, pers. comm.). Location of possible sturgeon spawning areas was studied in other rivers using fyke nets (Kohlhorst 1976), plankton nets and bottom trawls (McCabe and Tracy 1993), and artificial substrates (McCabe and Beckman 1990).

Female sturgeon release mature eggs that are brown, sticky and adhere readily to the substrate (Scott and Crossman 1973, Cherr and Clark 1985). The immature ova are retained (Welch and Beamesderfer 1993). Scott and Crossman (1973) noted that egg number varies with the size of female, from about 699,000 eggs for a medium sized female (16 kg, 2.4 m total length) to approximately 3-4 million eggs in the largest spawners; ovary weight can be as high as 113 kg. Released eggs are broadcast over large areas of river bed, with high velocity flows helping to disperse eggs and sperm, thereby ensuring that large egg masses are evenly spread over the substrate (Hanson et al. 1992). No direct observations are available on the spawning behaviour of white sturgeon in the Fraser River, but males could probably fertilize the eggs of several females.

2.3 FERTILIZATION AND LARVAL STAGE

Cherr and Clark (1985) studied gamete interaction in white sturgeon, and noted that ejected sturgeon eggs will remain viable for several hours while sperm motility decreases after five minutes. They also observed that the production by eggs of adhesive jelly is dependant upon the presence of calcium and/or magnesium in freshwater, but is not required for fertilization. As well, the white sturgeon spermatozoon exhibits an interesting and rare trait; namely, a filamentous protrusion on the anterior end of the sperm that forms upon encountering freshwater with magnesium or egg water. Those authors hypothesized that this growth serves to prevent interspecies fertilization.

Studies on white sturgeon larvae from the Sacramento River (Kohlhorst 1976) indicated that the incubation period may range from 5 to 25 days, with the longer period probably reflecting lower incubation temperatures. Laboratory studies by Wang et al. (1985) confirmed this, and showed that an optimum temperature range for incubation was 14-16°C, with larval mortality increasing outside the 10-20°C temperature range. Buddington et al. (1993) noted that this mortality was due to embryo's inability to modulate fatty acid composition of cell membranes to ensure proper fluidity. Manipulating maternal diet was suggested as a possible way to minimize these adverse responses.

Brannon et al. (1985) defined three larval stages for white sturgeon: dispersal, hiding and feeding. The dispersal stage generally lasts five days. The larvae, with their yolk sac still present, emerge in darkness and disperse with the current for distances over 175 km (Kohlhorst 1976, Stockley 1981, McCabe et al. 1989, Duke et al. 1990, and McCabe and Tracy 1993). During the next stage (hiding), larvae remain inactive and hidden under cover during daylight hours, then move out during darkness. This stage generally lasts until larvae are 14 days old. The final stage (feeding) occurs when the yolk sac is absorbed. Larvae begin to feed actively during daylight hours and, at approximately 18 days after hatching, their movements become totally related to the acquisition of food. Laboratory studies indicated that once feeding commenced, larvae showed no preference for cover and became less sensitive to light and changes in water temperature (Brannon et al. 1985). Other laboratory studies indicated that the searching and feeding rates of white sturgeon larvae were higher at higher stocking densities, but that higher food concentrations did not increase consumption (Gershanovich and Taufik 1992). This behaviour has not been confirmed in the wild.

After approximately 18 days, sturgeon larvae metamorphose to fry or young-of-the-year. Larval snout (rostrum) elongates, ventral surface flattens, and plates (scutes) appear on the dorsal, lateral and lateroventral body surfaces. After approximately 55 days, fry orient themselves in the current and swim freely, close to the substrate. Fry exhibit diurnal vertical migrations, rising into the water column at sunset, then descending to the bottom at sunrise. McEnroe and Cech (1985) tested the ability of juvenile (and adult) white sturgeon to tolerate salinity by osmoregulation, and observed that the ability to withstand rapid exposure to sea water increased with body size. No upper size limit was discovered at which this ability decreased.

2.4 JUVENILES

The type and geographic distribution of habitat utilized by white sturgeon juveniles is not well defined. Juveniles are known to migrate in lower reaches of large rivers, but these movements tend to be random, as indicated by studies in the Lower Columbia (Galbreath 1985). Lane (1991) asserted that white sturgeon juveniles in the Fraser River migrated between the mainstem and side-channels during summer months.

The first extensive field tagging study on juvenile sturgeon in the Fraser River was conducted at three backwater locations (Lane and Rosenau 1995). This study confirmed that juvenile sturgeon reside in sloughs and backwaters during summer months (winter sampling was minimal). All tags recaptured at the furthest upstream backwater location were previously tagged at that site. The next slough (5 km downstream) exhibited an identical tag recovery pattern. In the third slough (6 km further downstream), 90% of the recaptures were previously tagged at that site, while the remaining 10% were tagged in the slough upstream. Other evidence suggested that juveniles also utilize the mainstem. For example, small numbers of sturgeon juveniles were captured by beach seine in the lower Fraser mainstem in May during various field studies (pers. obs.), and also by anglers during summer months. However, Lane and Rosenau (1995) did not capture any juveniles at the mainstem sampling sites that exhibited uni-directional currents.

In exploring movements of sturgeon juveniles, Lane and Rosenau (1995) observed that higher catches of juveniles were obtained at water depths greater than 5 m (these depths resulting from tidal or seasonal flow changes), than at shallower depths. Those authors noted that water temperature increases above 13-15°C during spring months appeared to stimulate juvenile movement into backwaters, while a temperature decline below 13-15°C during summer months appeared to stimulate juvenile movement out of backwaters.

All sampling areas that yielded sturgeon had turbid waters. This is not surprising since sturgeon use primarily senses of smell, taste, touch and possibly electroreception when feeding (Buddington and Christofferson 1985). Loew and Sillman (1993) observed that white sturgeon acquired the ability to detect colour as they grew, and that colour vision possibly provides greater contrast detection in turbid waters. The larvae of white sturgeon apparently do not see colour, but possess photoreceptors designed for an exceptionally wide range of light conditions (from bright light to complete darkness, Sillman et al. 1990).

2.5 DIET

White sturgeon, like other sturgeon species, are mainly bottom feeders; their ventral barbels and protrusible mouths are well adapted for this type of foraging (Scott and Crossman 1973). The food of smaller sturgeon includes chironomids, mysids, molluscs, immature insect larvae and some zooplankton forms; in larger individuals (> 48 cm), fish constitute the principal food source (Scott and Crossman 1973). White sturgeon can digest different food types, and are ideally suited for digesting animal flesh (Buddington and Christofferson 1985). The following is a list of food items observed in sturgeon of different sizes during diet studies (cited in Hanson et al. 1992) involving Fraser River and other sturgeon stocks.

Sturgeon juveniles - less than 20 cm TL (total length)

- unidentified fry (Brannon et al. 1987),
- small crustaceans (Muir et al. 1988),
- adult Diptera (flies, gnats and mosquitoes) (Schreiber 1960),
- marine worms and American shad (Turner and Kelley 1966).

Sturgeon juveniles - 20-40 cm TL
- small crustaceans (Muir et al. 1988, Radtke 1966),
- marine worms and American shad (Turner and Kelley 1966),
- eulachon eggs (McCabe and Hinton 1990).

Sturgeon juveniles - 40-60 cm TL
- small crustaceans and sand-shrimps (Muir et al. 1988, Radtke 1966),
- eulachon eggs and small freshwater clams (McCabe et al. 1989).

Sturgeon - 60-80 cm TL
- small crustaceans, anchovies, eulachons (Muir et al. 1988),
- small crustaceans, sand-shrimps, small freshwater clams, marine clams found on sandy beaches, isopod crustaceans (Turner and Kelley 1966),
- sculpins, sticklebacks, lamprey, young sturgeon, chironomids (midges), crayfish, stonefly and mayfly larvae (Semakula and Larkin 1968),
- clams, snails, other fish, and small shrimp (*Daphnia)* (Cochnauer 1981).

Sturgeon over 80 cm TL
- eulachons, sculpins, sticklebacks, lamprey, young sturgeon, chironomids (midges), crayfish, stonefly and mayfly larvae (Semakula and Larkin 1968),
- adult salmon (S. McAdam, pers. comm.), clams, snails, small shrimp *(Daphnia)*, dungeness crab, brackish-water crab, starry flounder, Pacific herring and their eggs, plainfin midshipman, mussels, barnacles, many clam species and anchovies (Muir et al. 1988, Galbreath 1985, McKechnie and Fenner 1971, Bajkov 1949).

2.6 GROWTH, FEEDING AND NUTRITION

Data on white sturgeon growth and feeding comes from both field and laboratory studies. Growth is often expressed in terms of body length or weight-at-age. Typically when determining sturgeon age, pectoral fin sections are examined under a microscope and the number of annuli or "growth bands" is counted. Recent evidence, however, indicates a lack of accuracy and precision in this technique (Kohlhorst et al. 1980, Rien and Beamesderfer 1994). Age estimation studies on lake sturgeon by Rossiter et al. (1995) indicate that the close proximity of annuli in sturgeon over 18 years make individual bands difficult to distinguish leading to age under-estimation. Currently, no techniques are available to improve aging estimates. However, some researchers have used oxytetracyclene for aging validation (when injected into fish, this substance forms a fluorescent band on pectoral annuli). Unfortunately, these injections become unreliable reference points after a period of one to three years (Rien and Beamesderfer 1994).

Studies on growth rates of white sturgeon found along the Pacific Coast are numerous. Semakula (MS 1963) and Semakula and Larkin (1968) provided extensive data on the age and growth rates for Fraser River white sturgeon. Back-calculations by Semakula (MS 1963) showed that one-year old sturgeon juveniles varied in length from 12 cm to 37 cm (in Scott and Crossman 1973). The latter authors observed that white sturgeon generally reach a total length of approximately 50 cm by age 5, and grow about 50 mm per year to about age 25. Growth rate in length is slower after age 35, and growth is mainly in weight. Fraser River sturgeon females reached the following body sizes at ages 5 through 35:

WHITE STURGEON FEMALES IN FRASER RIVER *

Age (years)	Mean Fork Length	Mean weight of sample
5	0.49 m	-
10	0.77 m	3.5 kg
20	1.28 m	12.2 kg
30	1.84 m	-
35	2.04 m	49.9 kg

* Data from Semakula (MS 1963) as cited in Scott and Crossman (1973).

A 71-year old sturgeon female from Fraser River measured 2.3 m in fork length and weighed 79 kg (Semakula MS 1963); a Columbia River white sturgeon estimated to be 82 years old, measured 3.5 m (Scott and Crossman 1973).

Figure 5 shows the length-at-age data summaries (cited in Hanson et al. 1992). Age data were fitted using a von Bertalanffy (1938) growth function which minimizes the sum-of-squares of observed and predicted values. Based on these growth curves, a sturgeon from Nechako River may reach a length of 2.8 m by age 60 (Fig. 5). Beamesderfer (1993) developed standard weight equations for sturgeon where total body length is used to predict body weight, hence, this Nechako sturgeon would weigh an estimated 164 kg. This technique is used mainly in modelling where a standard weight index is intended to represent those fish in a better-than-average condition. Figure 6 graphically displays the estimated body weights for selected sturgeon stocks calculated using standard weight equations. As seen, Beamesderfer's (1993) calculations, although based on data from several biological studies and rivers, yielded very similar weight estimates for the different sturgeon stocks.

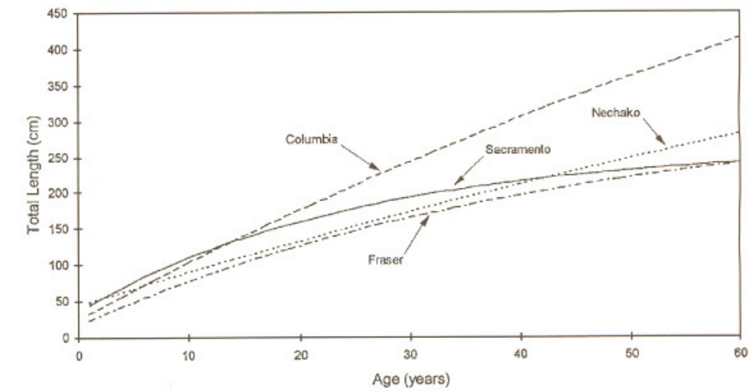

Fig. 5. Von Bertalanffy growth curves for selected Pacific Coast white sturgeon stocks (from Hanson et al. 1992).

Numerous laboratory studies on the growth and feeding of white sturgeon have been conducted, primarily for commercial production purposes. Hung and Lutes (1987) reported that juvenile white sturgeon grew optimally when fed 2% of their body weight per day (BW/day) using a high quality commercial feed, and a water temperature of

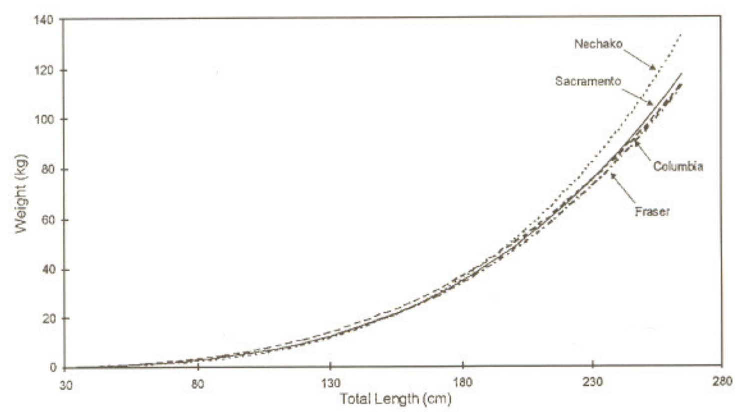

Fig. 6. Weight estimates calculated from total length using standard weight equations, for selected Pacific Coast white sturgeon (from Beamesderfer, 1993).

20°C. Similarly, Hung et al. (1989) reported optimal growth at a feeding regime of 1.5-2.0% BW/day and a temperature of 18°C. Growth rate increased with increasing water temperature up to 18-20°C (Lutes et al. 1990, Cech et al. 1984). Other studies found that growth and feeding rates increased with increasing water temperatures up to 26°C; however, a more efficient regimen was obtained at a slightly lower temperature of 23°C and a feeding rate of 2.0-2.5% BW/day, rather than 26°C and 2.5-3% BW/day (Hung et al. 1993). All researchers noted that survival was greater at lower water temperatures (~15°C).

Much of the nutritional information pertaining to sturgeon comes from laboratory studies on sturgeon juveniles. Hung and Lutes (1987, 1988) observed high growth rates using soya lecithin, and even higher growth rates using choline chloride (a component of lecithin). This was confirmed by Hung (1989) who recommended for optimum juvenile growth, a choline chloride content of 0.17 - 0.32% of the total diet by weight. Moore et al. (1988) found that white sturgeon juveniles (145 - 300 g) grew optimally when fed a good source of 40% crude protein. Swallow (1985) observed that white sturgeon apparently differ from other fishes in that sturgeon livers are unable to remove certain branched chain amino acids from peripheral blood; whether this is a physiological advantage is unknown. Fynn-Aikins et al. (1992) noted that white sturgeon can utilize dietary glucose for growth while many teleosts cannot do so. Also, white sturgeon are able to synthesize ascorbic acid (Vitamin C), while teleosts must acquire this vitamin by eating zooplankton (Dabrowski 1994).

Regarding food type, Lindberg and Doroshov (1986) demonstrated that juvenile white sturgeon showed a significant preference for natural Tubifex worms over a prepared biodiet. Stuart and Hung (1989) noted that sturgeon prefer softer foods. This was confirmed by Lutes et al. (1993). The latter authors and Buddington and Christofferson (1985) speculated that taste, texture and smell of feeds considerably affected feeding behaviour in white sturgeon.

2.7 MORTALITY AND DISEASE

Little is known about natural pathological agents in wild sturgeon populations. MacDonald et al. (1989) recorded the presence of a "Russian sturgeon nematode" (*Cystoopsis acipenseris*) in Fraser River white sturgeon; 11% of the 189 fish sampled were infested. Longer-term studies (1987-1991) on juvenile white sturgeon in the Lower Columbia River showed extremely variable year-to-year infestation rates (range 114%) with this nematode (McCabe 1993). This parasite was first observed in the Commonwealth of Independant States (CIS - formerly the USSR) during the late 1800s and has been known to infest a variety of sturgeon species. The intermediate hosts of *C. acipenseris* are amphipods which constitute a large part of the white sturgeon diet. Once consumed, nematode larvae burrow through the sturgeon's intestinal wall and surrounding tissue, until reaching the subcutaneous tissue. A trematode (*Nitzschia quadritestes*) is also known to occur in white sturgeon (Hoffman 1967). Little else is known about these parasites and their effect on stock mortality or morbidity rates.

White sturgeon propagated in hatcheries are known to acquire various bacterial infections (*Myxobacter spp.* and *Flexibacter columnaris*), protozoans (*Costia*), fungi, and a condition that inflates the sturgeon gut with gas, causing mortality (Conte et al. 1988). Viral pathogens are also reported. Hedrick et al. (1985) discovered adenovirus infections in the alimentary canal of sturgeon cultured from 1984 to 1986, with no subsequent detection. Hedrick et al. (1990) observed an iridovirus that attacked only the skin and gill surfaces of white sturgeon, subsequently causing its mortality. Hedrick et al. (1991) noted a herpesvirus that attacked the mouth and pharynx of white sturgeon. Further tests by Hedrick et al. (1992) indicated that the iridovirus would not transmit to lake sturgeon (*A. fulvescens*), striped bass (*Morone saxatilis*) or channel catfish (*Ictalurus punctatus*). Thus far, there has been no known contamination of wild stocks by aquaculture based diseases.

3.0 FRASER RIVER STOCK - GENETIC DESCRIPTION

Few genetic studies have been conducted on white sturgeon in the Fraser River. Most recently, Brown et al. (1992) conducted a mitochondrial DNA (mtDNA) analysis and suggested that Fraser white sturgeon had originated from the Columbia River population. Those authors hypothesized that during the last ice age (10,000-12,000 years ago), ice sheets receded from the Fraser Basin allowing Columbia white sturgeon to enter the Fraser system. Their main conclusion was that the effects of damming the Columbia River resulted in limiting the mtDNA diversity in the Columbia white sturgeon population, compared to the Fraser River stock. Those authors warned that other sturgeon stocks may suffer similar losses in diversity due to human intervention. However, other research based on electrophoretic analysis, suggested that Columbia River white sturgeon were genetically more diverse than the Fraser stock (Bartley et al. 1985). That study also indicated that sturgeon populations with access to the ocean exhibited more genetic diversity than land-locked populations. Hanson et al. (1992) suggested that the small sample sizes of Fraser River sturgeon may account for the differences in the above study findings. Nevertheless, Brown et al. (1992) reached an important and defensible conclusion; namely that reducing the genetic diversity of white sturgeon in the Fraser River may have serious consequences. As yet, no further genetic studies have been conducted.

4.0 STURGEON HARVEST MANAGEMENT ON FRASER RIVER

4.1 CURRENT MANAGEMENT PRACTICE

Federal and Provincial

Sturgeon in B.C. waters are caught in recreational fisheries, and also incidentally in commercial and aboriginal fisheries targeted at salmon. DFO manages all commercial and aboriginal fisheries in all B.C. waters (tidal and non-tidal), as well as recreational fisheries in tidal waters; the provincial agency, MELP, manages the non-tidal (freshwater) recreational fisheries. (In this report, "tidal" refers to brackish and marine waters, and "non-tidal" to fresh waters; Fraser River "tidal" waters are defined as those downstream of Mission Bridge, Fig. 1). Note that fishery regulations in B.C. do not differentiate between the white and green sturgeon species.

Currently, all commercial and recreational fisheries in Fraser River (upstream of river mouth) must release all caught sturgeon in accordance with the 1994 retention ban; while aboriginal fisheries in the Fraser have agreed to a voluntary release of incidentally caught sturgeon. However, catches of sturgeon in any B.C. marine waters fishery (outside the Fraser mouth) may be retained.

Prior to 1994, the sport fishing regulations on sturgeon differed markedly for tidal (DFO regulated) and non-tidal (MELP regulated) B.C. waters. Anglers in tidal waters could retain one sturgeon per day, while anglers in non-tidal waters were allowed to retain only one sturgeon per year (for regulation details, see section below on Recreational Fishery). Since 1994, a retention ban has been imposed jointly by the DFO and MELP, on any sturgeon caught in all recreational (and commercial) fisheries throughout the Fraser River. Poaching on sturgeon in tidal waters is believed to be significant, based on anecdotal reports from Fishery Officers and Guardians; however, funding is unavailable to collect adequate evidence for prosecution.

In the past, DFO research on Fraser River white sturgeon was limited to two tagging studies involving juveniles (MacDonald et al. 1987, 1989). Additional information on

Fraser white sturgeon was included with the Indian Food Fishery studies on salmon (Schubert 1984, 1985, 1986, 1994; and MacDonald 1987, 1988, 1989, 1990, 1991, 1992, 1994 prelim. data). At present, federal funds are limited for management activities involving Fraser River white sturgeon.

In the past, provincial management studies have focused on white sturgeon recreational fisheries. More recently, the MELP has funded (through the Habitat Conservation Fund), a series of studies dealing with the overall status of white sturgeon in the Fraser River. Lane and Rosenau (1995) were the first investigators to study the biology of white sturgeon juveniles in the lower Fraser below Hope. Currently, tagging studies on sturgeon are conducted in the mid- and upper portions of Fraser River, near Kamloops and Prince George, respectively.

Recently, MELP has taken an active interest in managing the freshwater recreational fisheries on sturgeon. This is not surprising as in the past, the majority (92% and 86%) of the respective aboriginal and recreational catches of sturgeon were taken in the Fraser River non-tidal waters (based on aboriginal catch data from Schubert (1984, 1985, 1986) and MacDonald (1987, 1988, 1989, 1990, 1991, 1992, 1994 prelim. data), and on recreational catch data from Inglis and Rosenau (1994) and Schubert (1994); see also Figure 10).

Inter-Ministerial

With increased media attention on white sturgeon in the Fraser River, efforts are being made by federal and provincial agencies to manage this resource jointly. The first tangible action was the 1994 retention ban on all sturgeon caught in commercial and recreational fisheries throughout the Fraser River. However, considerable uncertainty remains over the possible approaches to rebuilding the Fraser River white sturgeon population. In view of this, provincial and federal biologists have agreed to work cooperatively in developing an adequate plan.

4.2 STURGEON MANAGEMENT AND FISHERY CATCHES

Aboriginal Fishery

The aboriginal fishery had harvested white sturgeon for cultural and food purposes long before the Pacific Coast was settled. During the late 1800s, aboriginal peoples used to trade white sturgeon swim bladders (isinglass), flesh and roe. Prior to 1994, the aboriginal food fishery on sturgeon in the Fraser River was conducted throughout most of the year, except for occasional daily closures and brief closures during the winter. Currently, aboriginal fisheries in the Fraser River harvest sturgeon only incidentally, and all such catches may be voluntarily released.

Catch and effort in the aboriginal fishery on sturgeon have been monitored by DFO Fishery Officers and Guardians. The following fishing areas and gear types were designated:

FISHING AREA (Fig. 1)	GEAR TYPE
1. Steveston Area (below 9.6 km)	Drifted gill nets.
2. Deas Island (9.6-75 km)	Set gill nets.
3. Mission to Hope (75-151 km)	Set gill nets.
4. Hope to North Bend (151-206 km)	Set gill nets.

Gear counts were obtained from river, ground or aerial surveys. Catch and catch per unit effort (CPUE) statistics were estimated by direct observation or by interviews conducted once to several times weekly. Due to changes in fishery characteristics and in resource availability for monitoring, the estimation methods and the sampling intensity could vary within and between fishing areas throughout the year.

Catch and effort data for the aboriginal sturgeon fishery are available only for recent years (1983-1994). The data are reported in Schubert (1984, 1985, 1986), and MacDonald (1987, 1988, 1989, 1990, 1991, 1992, 1994 prelim. data). Note that these data may not necessarily represent numbers of sturgeon killed because field observations made by Fishery Officers and Guardians are sporadic and catch estimates are only approximate.

Figure 7 shows the estimated monthly catch and CPUE for sturgeon caught in the aboriginal fishery in lower Fraser during 1983-1991. The estimated monthly catches fluctuated widely from zero during winter months to over 1,000 pieces during summer months in some years; CPUE generally remained high during spring and summer months of each year. This seasonal pattern may perhaps be attributed to increased fishing effort and/or increased sturgeon availability in numbers, as well as possibly their greater vulnerability due to selection of more exposed habitat during warmer months. Apparent annual changes in the sturgeon catch and CPUE during the 1983-1991 period, may be due to actual changes in sturgeon abundance or to changes in sampling effectiveness. Figure 8 illustrates the relative distribution of estimated catch, effort and CPUE in the four fishing areas monitored in the lower Fraser River. Of these four areas, the highest portion of the total aboriginal catch and CPUE was observed in the Mission to Hope non-tidal waters.

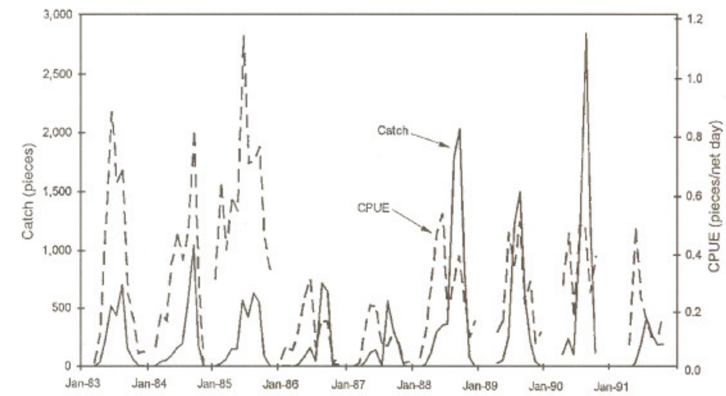

Fig. 7. Estimated monthly catch and estimated CPUE (places/net day) of white sturgeon in the Indian Food Fishery in the Lower Fraser River (km 0 to km 206), 1983-1991.

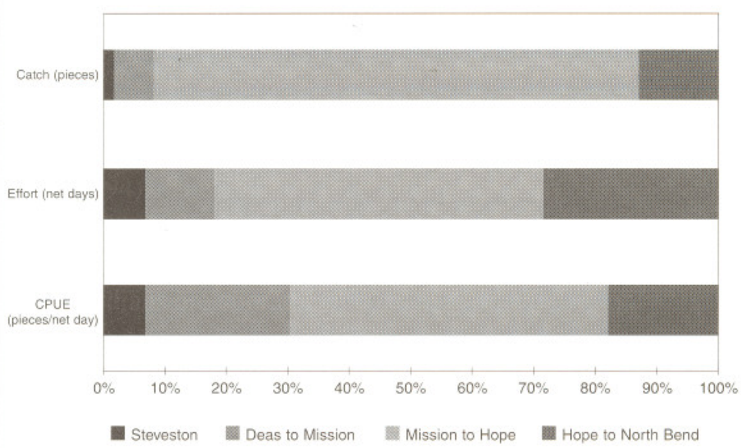

Fig. 8. Percent of the estimated catch, effort, and CPUE of white sturgeon, by fishing areas, in the Indian Food Fishery on the Lower Fraser River, 1983-1991.

Commercial Fishery

The Fraser River commercial fishery on sturgeon has been monitored since 1880. However, basic catch data, such as average body size, have not been collected, and catch statistics do not distinguish between the white and green sturgeon, making it difficult to evaluate the harvesting impact on each stock.

Figure 3 shows the estimated harvest (in tonnes) of sturgeon in the Fraser River commercial gillnet fishery during 1880-1993 (green sturgeon likely contributed significantly to the total harvest in earlier years). By the 1890s, the market for sturgeon flesh and roe had expanded eastward and poaching had become substantial. Annual landings of sturgeon increased dramatically, exceeding 200 tonnes in some years. However, this fishery crashed at the turn of the century, and in 1901, sturgeon in the Fraser River were considered commercially extinct (Semakula and Larkin 1968); nevertheless, they continued to be caught incidentally in gillnets targeting on sockeye salmon *(O. nerka)*. Catch, size and gear regulations were imposed, and the catch recovered somewhat, but then declined to below 20 tonnes annually despite regulations (Scott and Crossman 1973). More recently, lower landings of sturgeon were attributed in part to the closure of Fraser River chinook fishery since 1980 (M. Joyce, DFO, pers. comm.). Currently, sturgeon in the Fraser River are not targeted in any commercial fishery, and all incidental catches must be released in accordance with the 1994 retention ban.

Recreational Fishery

White sturgeon are esteemed in sport fishing publications for their excellent fighting qualities and palatable flesh, and sturgeon anglers are portrayed as dedicated to the pursuit of these large fish (Leanord 1987, Brunt 1993, Kristian 1994). Most anglers fish recreationally, but a small proportion operate as guides. As yet, no data are available on the latter commercial-recreational fishery. Currently, the recreational fishery on sturgeon in the Fraser River continues, but all captured fish must be released following the 1994 retention ban.

Interest in recreational fishing on sturgeon has increased dramatically since the late 1960s. In 1969, only 69 recreational sturgeon fishing permits were issued (Brunt 1993), but by 1985, the number of permits has increased 16 fold. In recent years, the number of non-tidal (freshwater) permits issued has increased from just over 1,000 in 1986 to over 3.000 permits by 1991 (Fig. 9).

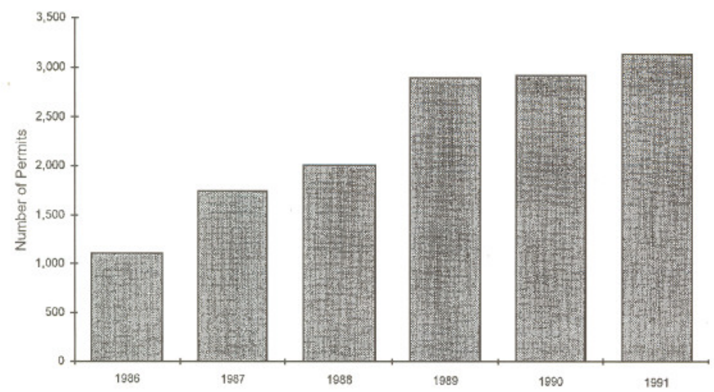

Fig. 9. Numbers of sturgeon fishing permits issued for the Fraser River recreational fishery in non-tidal waters, 1986-1991 (data from Inglis and Rosenau, 1994).

As stated earlier, sport fishing regulations for sturgeon were markedly different for the Fraser River tidal and non-tidal waters (managed by DFO and MELP, respectively) until 1994. Prior to this time, anglers in the Fraser tidal waters were permitted to retain one sturgeon per day within a legal size of over 100 cm fork length. On April 1, 1994, all Fraser tidal anglers were asked to voluntarily release all sturgeon over 150 cm in length, retaining only those fish in the 100-150 cm size range. In comparison, the Fraser River non-tidal sport fishery was allowed a bag limit of only one sturgeon per year, along with a size limit of 100-150 cm fork-length; this was a reduction from the 100-200 cm legal size limit prior to 1992 (Rosenau and Usher MS 1992). The aim of the above size regulations was to reduce harvesting of mature fish and of new recruits to the sport fishery.

Concerns by the DFO and MELP over the effectiveness of the above regulations alone to conserve the sturgeon population in Fraser River, and the potentially serious impact of poaching, prompted the two agencies to impose a retention ban in 1994 on all sturgeon caught in all recreational fisheries (tidal and non-tidal) in Fraser River. (That year, the DFO also imposed a retention ban on incidental catches of sturgeon by commercial fisheries in the Fraser; and requested for a voluntary release of incidental catches of sturgeon by aboriginal fisheries in the Fraser).

No historical catch data are available for recreational sturgeon fisheries in the Fraser River prior to 1985. However, Scott and Crossman (1973) observed that approximately 9,000-14,000 kg may have been harvested annually in a diffuse Fraser River sport fishery on sturgeon. Figure 10 shows the tidal and non-tidal sport catch statistics for the 1985-1991 period. During this period, most of the overall sport catch was taken in the non-tidal fishery, with over 2,000 releases estimated in some years. Of those fish caught in non-tidal waters, 77% were sub-legal in size (less than 100 cm in fork length); 85% of the legal-sized fish captured were retained; and of the total fish released, only 0.5% exceeded 200 cm in fork length (Inglis and Rosenau 1994). Size data are not available for sturgeon caught in tidal waters.

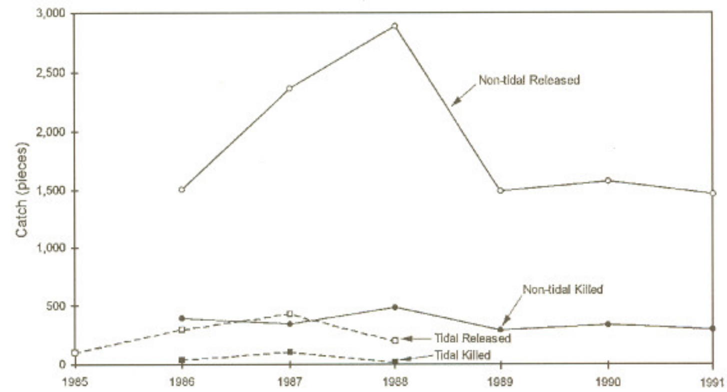

Fig. 10. Numbers of white sturgeon caught and released, or caught and killed, in each of the tidal and non-tidal recreational fisheries in the Lower Fraser River, 1985 - 1991 (data from Inglis and Rosenau, 1994 and Schubert, 1994).

Given the absence of any long-term studies on sturgeon exceeding 100 years in age, it is difficult to determine stock trends from recreational catch data. However, information collected by Inglis and Rosenau (1994) indicated that the average size of fish caught in non-tidal waters has increased, while recruitment of sub-legal fish has declined. It is not known whether this trend is a function of recruitment failure and/or increased efficiency by anglers to capture larger fish.

5.0 AQUACULTURE ACTIVITIES USING FRASER RIVER STURGEON

The only aquaculture facility in British Columbia that uses the Fraser River white sturgeon broodstock is located at Malaspina University College in Nanaimo, B.C. Of that total broodstock, 90% consist of the Fraser River fish and the remainder: California stock (Univ. California, Davis). The Malaspina research facility conducts experiments on sturgeon feeding behaviour, nutrition and habitat requirements; and long-term plans include a possible sale of hatchery-produced sturgeon juveniles to B.C. fish farms.

The first sturgeon broodstock was collected for the Malaspina facility in the mid-1980s from California, followed closely by Fraser broodstock, with subsequent successful incubation and rearing. While obtaining sperm from males does not appear to be a problem, obtaining mature eggs from females may be more difficult. For example, a large sturgeon female kept at the Inch Creek hatchery in Dewdney, B.C. (Harding 1987) has not been producing eggs. Pituitary injections have been attempted, and a proposal made to transport this fish to the Malaspina facility; there the fish would be subjected to elevated water temperatures (by 5°C) during winter months in an effort to induce egg production (this technique showed some success in

California). The above ongoing experiments are valuable in themselves, and also provide rare opportunities to observe directly the habits of white sturgeon.

Although no commercial aquaculture ventures involving Fraser white sturgeon are currently planned in B.C., interest has been expressed in this area through the above-mentioned project (at Inch Creek Hatchery), as well as a proposal for a feasibility study involving white sturgeon cultured in Chehalis River waters (Anon. 1986). This proposal was submitted to government agencies by Chehalis White Sturgeon Products, and stated that opportunities exist to produce and sell the following white sturgeon products:

1. Eggs surgically removed from wild sturgeon and sold as caviar,
2. Juveniles raised in a facility and sold to growers and aquarium suppliers, as well as possibly released in the wild for stock rebuilding, and
3. Adults raised in a facility and sold as a fish product.

At present, there is no update on the status of the Chehalis proposal. Also at this stage, it is difficult to define the limits, capacity, and product-use for any private aquaculture venture (in a rural community) that may consider sturgeon production.

In the United States, white sturgeon aquaculture has grown considerably. At the beginning of aquaculture development on the West Coast, Doroshov et al. (1983) reviewed the first successful attempts to rear sturgeon larvae and fingerlings in large numbers at the University of California, Davis. Those researchers used pituitary gland preparations made from carp and from sturgeon unsuitable for spawning, to induce ovulation in suitable females. Fertilized eggs were obtained by incision (resulting in female mortality); eggs were incubated in MacDonald incubators (18 litre glass jars with circulated water); and the resulting larvae were reared in circulating tanks or in an earthen pond.

All sturgeon larvae and sub-fingerlings were fed brine shrimp (*Artemia salina*), *Tubifex* and frozen herring, except for the small proportion of juveniles reared in the pond that fed on algae (*Moina spp.*) and small crustaceans (*Daphnia*). For juvenile growout, some fish were weaned to commercial feeds. Those juveniles that accepted a prepared diet grew at a higher rate than those fed a natural diet; however, the "prepared diet" group generally experienced reduced survival because many of these fish refused to feed. While the project was successful, problems arose with the lack of consistent success in spawning females of apparently similar ovarian development. Based on this study, recommendations were made to develop effective caesarean or cannulation techniques for egg removal without sacrificing females.

More recent studies indicated that spawning may be induced through injections of pituitary from white sturgeon, carp (*Cyprinus carpio*) or chum salmon (*O. keta*) (Lutes 1985); a more expensive synthetic compound is also available (Conte et al. 1988). Doroshov (1985), Kowtal et al. (1986), Conte et al. (1988) and D. Lane (Malaspina University College, pers. comm.) studied the fertilization of sturgeon eggs as it applies to aquaculture, and noted the ways to eliminate egg adhesiveness for fertilization (e.g. mixing eggs with fine clay or urea/sodium chloride solution).

Setbacks have occurred during aquaculture development in the U.S. In the late 1980s, outbreaks in California of the white sturgeon iridovirus resulted in large fish losses. Fortunately, this virus has not been detected since, although the possibility exists that sturgeon juveniles containing this virus may have been shipped out of California, mainly to overseas buyers (Hanson et al. 1992). At present, all U.S. state agencies enforce strict disease control programs and regulations.

As white sturgeon aquaculture developed, so did the need for economic analysis of commercial hatchery production. Shigekawa and Logan (1986) utilized baseline data from the Davis facility in California (data included brood size, feeding and stocking, growth and survival rates, and proportion of fish sold), and calculated the average total costs and the internal rates of return based on changes in facility size, stocking density and marketing strategy. Their analysis showed that investors could use an analytical approach to determine optimum facility type (a larger facility showed reduced production costs per unit), and optimum marketing strategy (marketed product could be sturgeon larvae, fry, fingerlings or 3-year olds). The model predicted higher, but less immediate profits, with an increase in the size of fish marketed.

The future of white sturgeon aquaculture as a market producer and stock enhancer in North America has become strengthened in view of recent experimental studies. However, in considering the problems in sturgeon culture, Doroshov and Binkowski (1985) stressed the need for North American fish culturists to learn from the greater experience of CIS scientists. Already, enhancement was recommended as a viable technique for rebuilding Columbia River sturgeon stocks which were impacted by effects of dams in that system (Brannon et al. 1984, Brannon et al. 1986). To date, most enhancement efforts on sturgeon in North America have been experimental, and their potential for stock rebuilding have yet to be demonstrated.

6.0 PRODUCTION ESTIMATES

Modelling efforts on sturgeon stock dynamics in relation to harvest or recruitment have included calculations of various stock production parameters. Natural survival rates per year for white sturgeon aged 5 years or older were estimated at 0.65 to 0.90 (Lukens 1985 and Kohlhorst et al. 1991, respectively). The estimated sustainable exploitation rate for white sturgeon has varied from 0.05 (Rieman and Beamesderfer 1990) to 0.24 (Lukens 1985). In this section, sustainable exploitation rate (SER) is defined as follows:

$$SER = (MSY) / (MSY + Escapement)$$

where MSY (maximum sustainable yield) is defined as the maximum annual harvest from a stock that does not impede that stock's ability to sustain itself in the long term. Semakula and Larkin (1968) estimated the sustainable exploitation rate for Fraser River white sturgeon at 0.13. However, Rieman and Beamesderfer (1990) analyzed the Columbia River sturgeon stock, and cautioned that long-lived species that have experienced intensive harvesting in the past were not likely to sustain exploitation rates greater than 0.05. Those authors further suggested that exploitation rates above 0.15 would collapse the fishery.

Several assumptions were made by Semakula and Larkin (1968) in their initial assessment of Fraser River white sturgeon production, where sustainable exploitation rate for sturgeon 11 years or older was estimated at 0.13. Those assumptions included density-independent recruitment from an unexploited stock of large fish. DeVore et al. (1993) also assumed constant recruitment for Columbia River white sturgeon and estimated the sustainable exploitation rate at 0.32. However, both sets of authors acknowledged that the above assumptions were unrealistic. Semakula and Larkin (1968) suggested conducting an experimental fishery on large-sized sturgeon for the purpose of providing density-dependent recruitment information. However, such a fishery would be an unlikely management choice at this time.

Given the extreme variability in age and weight at recruitment of Fraser River white sturgeon (Semakula and Larkin 1968), it is very difficult to ascertain the degree of density dependence or independence in stock-recruit relationships. Efforts to model recruitment density-dependence and independence exhibited high sensitivity to density-dependent assumptions at any exploitation rate (Rieman and Beamesderfer 1990, DeVore et al. 1993).

Other efforts by Echols (MS 1995) to model stock productivity under various harvest regimes and variable recruitment rates, showed model output to be sensitive to parameter change.

On an evolutionary level, the persistence of members of the sturgeon Family may reflect their successful resistance and/or adaptability to long-term changes in harvesting and/or habitat. However, with continued intensive harvesting and habitat degradation, the limits to sturgeon production remain uncertain. In the case of Fraser River white sturgeon, the extent of overall changes in habitat status and harvest intensity is unknown. Hilborn and Walters (1992) acknowledged that long-lived species, such as the sturgeon, usually provide very large yields at the inception of fisheries. Since the period of high sturgeon catches in the Fraser River occurred approximately 70 years before the beginning of harvest data collection, production potential of this stock is extremely difficult to estimate. As yet, no further production estimates for the Fraser sturgeon stock have been made.

7.0 PROPOSED INTERIM MANAGEMENT MEASURES

Based on the available (and inferred) information on white sturgeon in the Fraser River, we recommend the following measures to help protect and rebuild this population (note that these measures apply to both white and green sturgeon, since the two species are not readily distinguishable, and both appear to be in a serious decline in British Columbia).

1. Continue with the retention ban on all commercially and recreationally caught sturgeon in the Fraser River.
2. Investigate the feasibility of reducing incidental catches of sturgeon in B.C. salmon fisheries through different management strategies, such as selected time and area closures, and/or gear restrictions.
3. Increase public awareness of the problems of poaching and illegal sale of sturgeon in B.C., and encourage the reporting of such activities to fishery enforcement agencies.
4. Continue to fund and encourage further research on the Fraser River white sturgeon, and use the incoming information for the development of improved conservation strategies.
5. Develop a system for differentiating between the catches of white and green sturgeon in order to maintain separate records of catch and effort for these two species (this will be vital in the future when fishing on sturgeon in B.C. is reopened). One possible approach would be to subsample a wide range of fishery catches in the field for subsequent expert identification as to species, then develop "sturgeon catch composition ratios" by season and catch area. These ratios could then be applied to sturgeon catches in the various fisheries.

8.0 INFORMATION STATUS

The information summarized in this report on the Fraser River white sturgeon points to weak areas in the research and management of this species. Limited funding and public support, as well as unproven experimental techniques all contribute to these deficiencies. Recently MELP has taken steps to begin the process of collecting and analyzing data on Fraser River white sturgeon in order to promote their health and ensure benefits to B.C. communities. The following list outlines potential studies and projects designed to achieve these objectives. The list was based on considerations and comments derived from studies and articles mentioned in this report. The suggested studies are intended to stimulate discussion, and represent no policy or official view of either DFO or MELP.

1. Program Development
   - Development of research and management objectives for the Fraser River white sturgeon.
   - Consultation with users to assist in the development of specific goals.
   - Assessment of funding requirements and their availability.
   - Development of methodologies for program evaluation.
2. Field Studies
   - Larval dispersal, hiding and feeding habitats.
   - Diet and nutrition.
   - Migration and distribution of juveniles and adults in marine and/or fresh waters.
   - Age and size at maturity, and intervals between successive spawnings.
   - Spawning locations and behaviour.
   - Parasite and disease identification.
   - Genetic diversity studies.
   - Catch monitoring programs.
   - Documentation of poaching activities.
   - Techniques for improving habitat.
3. Laboratory Studies
   - Determining critical life requirements (e.g. critical temperature and oxygen levels).
   - Assessing validity and reliability of ageing techniques.
   - Studying morbidity and mortality from parasites and pathological agents.
   - Developing treatments for parasitic and disease infections.
4. Economic and Social Analysis
   - Cost/benefit analysis of sturgeon management initiatives.
   - Economic modelling of aquaculture feasibility as it applies to commercial and enhancement activities.
   - Opinion surveys of users, managers and/or general public.
5. Tools and Techniques
   - Field and laboratory sampling design and evaluation.
   - Sturgeon database design and development.
   - Models involving biomass, recruitment, growth and mortality, to help predict stock dynamics and the effects of management strategies.

Scientific research and management strategies for the Fraser River white sturgeon have been largely ignored in the past. Unless these concerns are addressed promptly, Canada's largest freshwater fish may join the Alabama (*Scaphirhynchus suttkusi*) and pallid (*S. albus*) sturgeons on the list of endangered North American fishes (Waldman, 1995). Indeed, the continued presence of white sturgeon in the Fraser River is surprising, given the intensive harvesting of this species in the past, and decades of habitat disturbance and degradation. It is hoped that with the recent growth in research and management activities on this species, and with the co-operation between federal and provincial fisheries managers and users, the sturgeon population in B.C. will continue to represent one of Canada's unique fish groups.

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Appendix 1. Information on green sturgeon in British Columbia.

The green sturgeon (*Acipenser medirostris*) is the only other sturgeon species (besides white sturgeon) inhabiting the West Coast Pacific area (it is not found on the Atlantic Coast of Canada). Green sturgeon are found primarily in marine waters (Scott and Crossman 1973), but can also be found in fresh waters, as indicated by their capture in the Fraser River sockeye fishery. Sturgeon landings reported in the B.C. Commercial Catch Statistics do not differentiate between green and white sturgeon, and these two species may be often confused in identification attempts. As a result of these two factors, it is difficult to estimate the historical catches of green sturgeon in B.C. waters .

The following physical differences are reported between the green and white sturgeon (based on Scott and Crossman 1973, Lane 1991, and Foley 1995 Memo):

PHYSICAL DIFFERENCES BETWEEN GREEN AND WHITE STURGEON	
1. Body Cross Section	More pentagonal than in white sturgeon.
2. Head Size	Longer than in white sturgeon.
3. Nose (snout)	Longer than in white sturgeon, with barbels closer to mouth than snout tip.
4. Gill Rakers	Shorter and broader than in white sturgeon, 18-20 on first arch (white sturgeon have 34-36 long, narrow gill rakers on first arch).
5. Dorsal Fin	33-35 rays (white sturgeon have 44-48 rays).
6. Plates (scutes)	Dorsal plates 9-11 (white sturgeon 11-14); lateral plates 23-30 (white sturgeon 38-48); ventral plates 7-10 (white sturgeon 9-12); and 1-2 plates between the dorsal and caudal fins (none in white sturgeon).
7. Dorsal plate morphology	Tip of spine (spiracle) on dorsal plates is posterior to plate insertion (where plate and skin meet) on green sturgeon (but central on white sturgeon).
8. Post-vent plates (scutes)	Viewed ventrally, green sturgeon have one row of 1-4 post-vent plates (but two rows in white sturgeon).
9. Vent Location	Viewed ventrally, the anus on green sturgeon lies between the anal fin insertions (but posterior to these insertions in white sturgeon).
10. Body Colour	Green sturgeon range from dark green to slightly olive; same colour stripe on underside of green sturgeon running down the centre and a stripe on lower half of each side (white sturgeon have no stripes and tend to be grey in colour). However, colours may be identical between individual green and white sturgeons.
11. Body Size	Maximum reported body length of 2.1 m.

Artyukhin and Andronov (1990) studied green sturgeon populations in rivers of the former USSR. They observed that adults spawn in relatively small rivers; the young rear in lower river reaches, then migrate to marine waters upon reaching maturity. Those authors indicated that adults and large juveniles often migrated to feed in lower reaches of several coastal rivers. They also hypothesized that white and green sturgeon possess similar ecological characteristics and have a common evolutionary ancestor. Whether these observations can be applied also to the populations of green sturgeon in B.C. is not known.

Houston (1988) reviewed habitat concerns and status of green sturgeon in Canada, and noted that this species appears to be uncommon. While Houston (1988) did not place much importance on the impact of harvesting green sturgeon, new information suggests that these fish may have been harvested in Canada in considerable numbers.

Terry Slack (a commercial gillnetter in B.C.) recently posted a notice in a popular B.C. commercial fishing magazine requesting incidental reports on the catches of green sturgeon (pers. comm.). He received 15 such reports, dating back to 1952 and including some from recent years. These reports dealt with individual fish caught by seiners, gillnetters, longliners and recreational fishers, as well as some larger catches made by trawlers. It is believed that the reported fish were green sturgeon in most cases, since the vast majority of sturgeon caught in B.C. marine waters consist of this species (N. Venables, DFO, pers. comm.). Any misidentification that may have occurred would be primarily in the lower Fraser area where both green and white sturgeon may be found. In addition, recent reports of white sturgeon from Alberni Inlet (mentioned previously) indicate the potential for misidentification province wide of white sturgeon are able to travel long distances in tidal waters.

Individual green sturgeon, cited in the above reports, were caught mainly in the lower Fraser River, the North Coast of B.C., Queen Charlotte Islands, Strait of Georgia and the West Coast of Vancouver Island (WCVI). Trawlers from the WCVI had recalled large sturgeon catches of up to 10,000 lb (~4,500 kg) taken from 30 to 60 fathoms (~55-110 m depth) in marine waters during the early and mid-1980s. Those catches included sturgeon taken in more sheltered waters such as the Barkley Sound and Nootka Sound. While the above reports may not be useful for stock assessment purposes, they do indicate an apparent decline over time in catches of green sturgeon. As with white sturgeon, there are concerns regarding the impact of poaching on green sturgeon.