STATUS OF WHITE STURGEON IN THE LOWER FRASER RIVER

REPORT ON THE FINDINGS OF THE LOWER FRASER RIVER WHITE STURGEON MONITORING AND ASSESSMENT PROGRAM 2006

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VANCOUVER, BC

NOVEMBER 2007

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EXECUTIVE SUMMARY

The province of British Columbia has a responsibility and a long-standing interest in the conservation, protection, management, and assessment of Fraser River white sturgeon (*Acipenser transmontanus*). The Fraser River Sturgeon Conservation Society (FRSCS), a not-for-profit charitable organization founded in 1997, has a mandate to conserve and restore Fraser River white sturgeon stocks, raise public awareness regarding Fraser River sturgeon and their ecosystem, and gather reliable information on sturgeon and their habitat in an effort to develop and promote effective conservation programs. Both the province of British Columbia and the FRSCS recognize that there is a distinct need to provide reliable estimates of the population size and structure of white sturgeon in the lower Fraser River downstream of Mission, and to increase the confidence in the estimates of white sturgeon abundance in the section of river from Mission to Hope, to assist in their conservation mandates. This report presents an update of program activities and population assessments (as of January 2007) for the Lower Fraser River White Sturgeon Monitoring and Assessment Program from its beginning in October 1999 through December 2006.

The study applied the coordinated efforts and in-kind contributions from true stewards of the resource: angling guides, recreational, commercial, and Aboriginal fishermen, test fishery and enforcement personnel, and various fishery monitors. These volunteers were trained to sample, tag, and record and transfer data. In April 2001, the program incorporated a Lower Fraser River First Nations White Sturgeon Stewardship Program as a strategic and parallel component of the core monitoring and assessment program. By December 2006, volunteers from the combined programs had tagged and released 30,409 sturgeon, sampled over 47,000 sturgeon for the presence of a tag, and documented 11,898 recapture events of tags applied by the FRSCS programs. In-kind contributions of time and equipment (boats, vehicles, sampling equipment) from FRSCS volunteers exceeded $500,000 per year.

A descriptive population model has been developed to provide reliable estimates of the population of white sturgeon in the lower Fraser River, by size/age group and location, based on tag release and recapture. The population component of the model considers tag distribution and seasonal mixing, and is sensitive to estimates of mortality, emigration, and observer error. The model also describes patterns of inter- and intra-annual movements, and specific feeding and overwintering behaviors, by size/age group.

As of December 2006, the population estimate for white sturgeon (from 40-260 cm fork length) in the lower Fraser River was 46,957. This mean population estimate is 25% less than the 2003 mean estimate of 62,611. Comparative population estimates of the numbers of sturgeon before and after January 2003 strongly suggest a decrease in the overall population of sturgeon, with the greatest decreases occurring in young juvenile sturgeon (less than 100 cm fork length).

INTRODUCTION

The British Columbia Ministry Environment (MOE) is tasked with the maintenance of biological diversity within British Columbia. Issues regarding the conservation of biological resources and species at risk in the province are best addressed through rigorous science. For species of concern, a thorough understanding of the biology, ecology, and habitat requirements of the specific species is the foundation from which specific conservation actions can be developed. Key to conservation biology is reliable information on distribution, abundance, age structure, and recruitment, and overall stock status. If any of these crucial information areas are lacking, those data gaps need to be addressed in order to move forward with conservation and/or resource management initiatives.

Since the early 1900s, white sturgeon have been identified as a species of concern in British Columbia (Lane 1991, Echols 1995). From 1995-1999, the BC government conducted studies to collect biological and ecological information on white sturgeon throughout the Fraser River watershed (RL&L 2000). Most of the information currently available for sturgeon populations above the Fraser canyon was obtained through these studies. Information regarding distribution and abundance in the lower Fraser River was viewed as preliminary due to the wide confidence intervals of the population estimates and the limited geographic scope undertaken in this portion of the river (upstream of Mission only). The 5-year study produced an estimate of 976 adult and subadult sturgeon for the river reach from Yale to Hope (range from 601 to 1598; 95% CI; RL&L 2000). The estimates for the number of adult and sub-adult sturgeon living in the eastern Fraser Valley section of the river, from Hope to Mission, was 17,259 fish, with a range of 6,118 to 64,338 (RL&L 2000). From a technical perspective, these values were not robust enough for proper sturgeon management and the development of a rigorous recovery program. Furthermore, the 1995-99 study did not include any assessments of white sturgeon abundance or distribution downstream of the Mission Bridge (an extensive area that includes 79 kilometers of Fraser River mainstem, plus additional sturgeon-bearing waters including the North Arm and Middle Arm of the Fraser River, and Pitt River/Pitt Lake). The lack of population estimates, migration patterns, and seasonal distribution information for white sturgeon in this portion of the lower Fraser River and estuary was considered to constitute a serious data gap by provincial fisheries managers (RL&L 2000).

In response to these shortcomings, a proposal from FRSCS was put forth to the provincial government in November 1999 to develop a more comprehensive and scientifically rigorous white sturgeon population estimate for the lower Fraser River. This proposal resulted in support for a pilot project (November 1999 through March 2000), which was highly successful in terms of demonstrating that the technical components were achievable for the expanded program. The key to this expanded study was the ability of the FRSCS to secure a large body of volunteer effort from the public, in concert with a scientifically and technically rigorous study design. As a result of these successes, the Lower Fraser River White Sturgeon Monitoring and Assessment Program began in earnest in April 2000.

Program Background

The challenge of building a true “stewardship” initiative for lower Fraser River sturgeon was embraced by the FRSCS during a pilot project phase from October 1999 through March 2000. The response by project volunteers and the high level of commitment and dedication exhibited during the pilot phase provided sufficient confidence to continue and expand the volunteer-based project activities. Thus, in April 2000, sponsorship from the Habitat Conservation Trust Fund (HCTF) and Fisheries Renewal BC provided the means to purchase tagging and sampling equipment, expand volunteer training and quality assurance activities, secure and manage data, and commence the construction of an analytical model for population estimation.

In April 2002, a significant contribution from a private donor, the North Growth Foundation, made it possible for the FRSCS to hire a full-time Executive Director. This organizational change provided the means to lever grant funds, and allowed the Society to continue the significant monitoring and assessment program while developing additional, strategic and stewardship-based projects and programs, including a Lower Fraser River First Nations Sturgeon Stewardship Program and the initiation of a watershed-wide Fraser River White Sturgeon Conservation Plan.

The program designs presented in this document were initially constructed by LGL Limited environmental research associates (Sidney, BC) in consultation with the FRSCS. Analytical procedures and methods described in this document were constructed by W. J. Gazey Research (Victoria, BC) in consultation with LGL Limited and the FRSCS. Approvals for sampling methods, which included sturgeon capture and handling practices, were obtained following reviews by provincial and federal permitting authorities and the subsequent issue of respective provincial and federal sampling permits. Applied program designs described in this document expand on the geographic scope of the 1995-99 Fraser River white sturgeon monitoring program (RL&L 2000). Program results presented in this document are preceded by results presented in Nelson et al. (2004).

Program Objectives

The primary objectives for the project were to:

1) produce an estimate of the number of sub adult and adult white sturgeon in the lower Fraser River, with an emphasis on the section downstream of Hope;
2) produce reliable information regarding seasonal abundance of white sturgeon, by location, in the lower Fraser River;
3) produce information on the seasonal migration and movement patterns of white sturgeon in the lower Fraser River; and
4) increase public awareness regarding the conservation and preservation of white sturgeon in BC.

Brief Overview of White Sturgeon

The white sturgeon is the largest freshwater fish in Canada and North America, attaining lengths to 6.1 m and confirmed weights from the Fraser River to 629 kg (Scott and Crossman 1973). The physical structure of white sturgeon has changed little since the late Jurassic, showing that the species has been able to adapt and adjust to dynamic environmental changes. In the Fraser River watershed of BC, white sturgeon have been documented from the Fraser estuary to upstream tributaries over 1040 km upstream (including the Nechako, Stuart, and Bowron, and Torpy rivers north of Prince George; Nelson 1997, RL&L 2000).

The white sturgeon first appeared in the scientific literature in 1836 in Sir John Richardson's epic Fauna Boreali-Americana as *Acipenser transmontanus*, or the sturgeon from "across the mountains" (Glavi94). Mature specimens can attain large size proportions; the body is subcylindrical with five rows of hooked plates (scutes) over smooth skin. The large mouth is ventral, toothless, and protrusile. From a divergence in the pre-Jurassic, the Infraclass Chondrosetei (sturgeons and paddlefishes) maintained a cartilaginous skeleton while the teleost fishes ossified their frames (Brown et al. 1992). The sturgeons (family Acipenseridae) include four genera: Huso, Acipenser, Scaphyrhynchus, and Pseudoscaphyrhynchus. Five species of sturgeon exist in Canada, and all species are of the genera Acipenser: 1) the white sturgeon (*A. transmontanus*); 2) the Atlantic sturgeon (*A. Oxrhynchus*); 3) the green sturgeon (*A. medirostris*); 4) the lake sturgeon (*A. fulvescens*); and 5) the shortnose sturgeon (*A. brevirostrum*). The white and green sturgeon are the only sturgeon species in Canada present west of the Rocky Mountains.

White sturgeon are facultatively anadromous, as stocks with access to estuarine and marine habitats may utilize these environments; however, they spawn only in freshwater. The species does not require the marine environment as part of its life history; landlocked stocks are known to reside and spawn in the Columbia and Kootenai rivers (Beamesderfer and Nigro 1995). White sturgeon are dispersed along the eastern Pacific coast from central California to the Gulf of Alaska, with occurrences in several small coastal estuaries and rivers (i.e., the Klamath and Smith rivers in northern California; the Umpqua River and Yaquina and Tillamook bays in Oregon; Grays Harbor and several areas of northern Puget Sound in Washington; the Skeena River and inlets on both the east and west side of Vancouver Island in BC). These occurrences, however, are likely migrating or feeding fish that originated in one of the larger three watersheds where spawning has been documented (the Sacramento, Columbia, and Fraser rivers; Galbreath 1985).

The basic components of what is known about white sturgeon life history are summarized in Scott and Crossman (1973), with Fraser-specific components provided in Perrin et al. (2003). Characteristics critical to this study are:

a. the spawning period is usually from May through July, but could be later for stocks with long freshwater migrations;

b. spawning probably takes place over rocky bottom in swift current when water temperatures are between 11.3 and 18.4 ^{o}C;
c. adults survive spawning and return to spawn more than once, but only after increasing intervals of years. In younger females the interval is 4 years, and 9-11 years in older females;
d. first spawning in Fraser River white sturgeon probably takes place between 11 and 22 years of ages for males (roughly 80-130 cm in length), and in females between 26 and 34 years of age (roughly 130-200 cm); and
e. lower Fraser River white sturgeon were shown to spawn in large side channels between Hope and Chilliwack (Perrin et al. 2003).

Intensive commercial fishing pressure in the late 1800s and early 1900s reduced the historical abundance of white sturgeon in the lower Fraser River to dangerously low levels (Semakula and Larkin 1968, Echols 1995). Since this time, lower Fraser River white sturgeon have faced numerous obstacles on the path to population recovery; these include: 1) critical habitat degradation/reduction; 2) a reduction in overall food availability, including all salmon species and Pacific eulachon (*Thaleichthys pacificus*; Hay et al. 1999); 3) kill fisheries (commercial, recreational, First Nations, and illegal/poaching); and 4) both freshwater and estuarine pollution (Nelson and Levings 1995). In 1993 and 1994, an unexplained die-off of over 30 large, mature sturgeon occurred over a relatively short period of time. Fraser First Nations called on the resource management agencies to eliminate all harvest of sturgeon in British Columbia. In 1994, the province changed the recreational fishing regulations for sturgeon from (limited) retention to catch-and-release fishing only, while all commercial fisheries (managed by Fisheries and Oceans Canada) were required to release all incidentally caught sturgeon. Also in 1994, Fraser First Nations imposed voluntary moratoriums on directed (Aboriginal) white sturgeon fisheries and encouraged the release of white sturgeon intercepted during all non-targeted Aboriginal fisheries. Because provincial fisheries managers were uncertain as to the abundance of white sturgeon throughout the Fraser River watershed, an active research program, funded by the HCTF, was initiated by the province in 1995 (Echols 1995).

Immigration and Emigration

It is well documented that white sturgeon on the Pacific coast are capable of extensive migrations both within and between major watersheds (those being the Sacramento River watershed in California, the Columbia River watershed of Oregon and Washington, and the Fraser River in BC). Tagging studies have confirmed sturgeon movements among these watersheds (Stockley 1981, Galbreath 1985, DeVore et al. 1995, this study). Substantial tagging programs for white sturgeon in the lower Columbia River have produced numerous recaptures from several coastal bays and inlets in Oregon and Washington, and in Puget Sound (Galbreath 1985).

New analytical techniques that use laser ablation sampling to determine levels of strontium in fin rays of Fraser River white sturgeon (Vienott et al. 1999) suggest low frequency of marine migrations for lower Fraser River white sturgeon. However, this work (Vienott et al. 1999) also suggests limited juvenile rearing in brackish waters (the Fraser estuary).

Legal Listings

From the onset of the FRSCS white sturgeon program in October 1999, through November 2003, white sturgeon in Canada were designated as a "Species of Special Concern" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). In 2003, COSEWIC, in collaboration with MOE, concluded a review of the status of white sturgeon in Canada; the COSEWIC review identified a total of six distinct "stocks" of white sturgeon (all of which occur in BC) based on both geographic (watershed) separation and genetic distinction. The six Canadian white sturgeon stocks identified by COSEWIC are: 1) Kootenay River; 2) Columbia River; 3); Nechako River; 4) upper Fraser River; 5) middle Fraser River; and 6) lower Fraser River. Based on numerous criteria including abundance and stock status (for each individual stock), the COSEWIC review listed all six stocks of white sturgeon as "Endangered" (see 28 November 2003 COSEWIC press release: http://www.cosewic.gc.ca). Currently, the provincial Conservation Data Center (MOE) lists lower Fraser River white sturgeon as "Imperiled" (classification Red, rank S2).

The Species at Risk Act (SARA), which became law in June 2003, requires that all species designated "at risk" under COSEWIC are additionally reviewed through an additional SARA process for consideration of legal protection ("listing") under the Act. For white sturgeon, this process commenced in 2005 and concluded in August 2006. Reviews were conducted on a stock-specific basis as per the COSEWIC designations (i.e., separate considerations for each of the six stocks identified). Following a 14-month process that included public consultation and stakeholder input, the final decision (delivered from the federal Cabinet) regarding SARA listing for white sturgeon was that four of the stocks (Kootenay River; Columbia River; Nechako, and upper Fraser River) were adopted for SARA protection and two of stocks (middle Fraser River and lower Fraser River) were not. The rational for not SARA-listing the middle and lower Fraser River white sturgeon stocks was "based on the potential negative socio-economic impacts a listing decision would have on Aboriginal peoples and the sport fishing industry" (Canada Gazette 2006).

FIELD AND ANALYTICAL METHODS

Study Area

The sampling area for this study spanned the mainstem of the Fraser River from Yale to the Strait of Georgia, and included the Harrison River, and the Pitt River and lake (Figure 1).

Sampling “regions” were established within the broad study area, and were used for analyses and reporting (Figure 2). The sampling “regions” were further sub-divided into sampling “zones” (Figure 3) for the purpose of more detailed analyses. Both sampling regions and sampling zones were determined from specific river kilometer data entries associated with release and recapture data; river kilometer entries were based on a standardized mapping system and were recorded to the nearest 0.5 km.

Data Recording

All volunteers that contributed to the tag and recapture database were trained by program staff. Volunteers were trained in the field, typically on their own boat, including recreational fishing boats, angling guide boats, First Nation and commercial fishing boats, enforcement (patrol) boats, and test fishery vessels. The sampling and tagging of at least one sturgeon was required to fulfill the training requirements and, typically, several sturgeon were captured and tagged during training exercises. Volunteers were trained to complete a standard sampling data sheet (see Appendix A), scan captured sturgeon for the presence of a PIT tag, record all tag recapture data (from any PIT tag or external tag), apply new PIT tags, take fork length and girth measurements, revive and release sturgeon, and secure and transfer the data. In addition, an application of “best practices” regarding sturgeon handling was requested of all volunteers. For volunteers that captured sturgeon by angling, this activity included the use and correct application of adequate fishing equipment (strong rods and reels, line test of at least 100 pound breaking strength), and the employment of legal and ethical fishing conduct. For commercial and First Nation net fishermen involved with the program, emphasis was placed on extreme care when removing sturgeon from gill nets, and efficient sampling practices to ensure that captured sturgeon were returned to the water as quickly as possible. Some First Nation fishermen associated with an associated FRSCS sturgeon sampling program, the Lower Fraser River First Nations White Sturgeon Stewardship Program, placed captured sturgeon in floating enclosures, anchored in close proximity to fishing locations.

Fish Handling Procedures

A "fish-first" policy has prevailed throughout this program. All volunteers were instructed to handle captured sturgeon quickly and carefully to minimize stress and ensure a high condition factor at release. The procedure for handling sturgeon for sampling was based on the size of the fish and the style of boat being used. From most boats, small sturgeon (less than 1 m in length) were carefully placed in a custom "sturgeon sling" (a stretcher), that contained water, or into an extra-large, water-filled tub (used on some commercial and First Nation fishing vessels). Most sturgeon from 1-1.5 m in length were also lifted into a sling, given that the type of boat being used could accommodate this action (this was difficult in large boats with high sides); otherwise, these sturgeon, and most other sturgeon larger than approximately 1.5 m, were sampled in the water, either alongside the boat or at the beach.

Documentation of Capture Location

River Kilometer

A simple mapping system was established to document capture locations to the nearest 0.5 km. Waterproof maps, delineated with river kilometers, were provided to all volunteers as part of the tagging equipment kit. Documentation of sturgeon capture location at this level (0.5 km) was important to document sturgeon presence and absence at specific locations and habitat types, by season.

Zone

In order to document the general location of applied angler effort and catch, a series of sampling "zones" (adjacent sections of the river) were established. The utility of information at the “zone” level is most evident when catch, catch-per-effort, and recapture data are compiled.

Zone		From	To
1(N)	(North Arm)	Georgia Strait	Eastern Annacis Island
1(M)	(Middle Arm)	Georgia Strait	Entrance of North Arm
2(S)	(Main/South Arm)	Georgia Strait	Eastern Annacis Island
2(C)	(Canoe Pass)	Georgia Strait	Entrance at South Arm
3	(Fraser Mainstem	Eastern Annacis Island	Port Mann Bridge
4	(Pitt River)	Hwy 7 Bridge	Upstream Pitt River
5	(Fraser Mainstem)*	Port Mann Bridge	Albion Ferry Crossing
6	(Fraser Mainstem)	Albion Ferry Crossing	Mission Bridge
7	(Stave River)	Confluence with Fraser	Upstream Stave River
8	(Fraser Mainstem)	Mission Bridge	Mouth of Sumas River
9	(Nicomen Slough)	Confluence with Fraser	Upstream end of Slough
10	(Harrison River)	Confluence of Fraser	Outlet of Harrison Lake
11	(Harrison Lake)	Outlet of Harrison Lake	Inlet of Harrison Lake
12	(Fraser Mainstem)	Mouth of Sumas River	Agassiz Bridge
13	(Fraser Mainstem)	Agassiz Bridge	Hyw 1 (Hope) Bridge
14	(Fraser Mainstem)	Hyw 1 (Hope) Bridge	Lady Franklin Rock (Yale)

* Zone 5 includes 4 kms of the Pitt River (downstream of the Hwy 7 Bridge)

Not all designated zones were usimatn the population estimations presented in this report (see designations presented in Table 1). Note that zones 2(S) and 2(C) are combined in the population analyses and labeled as zone S (South Arm of Fraser that includes Canoe Pass).

Tagging

PIT Tags and Tag Readers

The tags used for this study are Passive Integrated Transponder (PIT) tags, distributed by Biomark Inc. These tags are injected beneath the skin of sturgeon with a specialized, hand-held syringe and hypodermic needle. No external tags were deployed during the study. PIT tags are electronic tags that do not contain a power source (such as a radio or acoustic tag) and must be "read" with a PIT tag scanner. Both the TX1400L (12 mm long) and TX1405L tag (14 mm long) were used in this study; both glass-bodied tags are 2 mm in diameter and emit a unique 10-digit alpha-numeric code at a frequency of 125 kHz. PIT tags were kept in small glass or plastic jars that contained ethyl alcohol for sterile purposes. Hypodermic needles used to apply the tags were also kept in small jars that contained ethyl alcohol.

Sturgeon are tagged with PIT tags inserted at a location just posterior to the bony head plate, left of the dorsal line, near the first dorsal scute. This PIT tag insertion location has been used by sturgeon researchers in both Oregon and Washington, and measured tag retention has been close to 100% (Tom Rien, Oregon Dept. of Fish and Game, pers. comm.). Other sturgeon tagging studies in the Fraser River applied PIT tags in body locations other than the "head" location (the dorsal-lateral area or body cavity). Sturgeon recaptured during this study that had a PIT tag present in an area of the body other than the "head" location received an additional tag in the "head" location. Sturgeon that were recaptured with a functional PIT tag in the head location were not provided with an additional tag. Tag recapture data for all tags, regardless of tag type or body location, was recorded and entered in the recapture database.

The tag readers (scanners) used for the program were the hand-held model MPR (distributed by Biomark, Inc.) and the AVID Power Tracker (distributed by AVID Canada). The readers are battery powered, and display the tag numbers on a small screen. An audible "beep" is emitted by the reader when it detects a tag. When a captured sturgeon was ready for sampling, a reader was used to scan for the presence of a tag (a recapture). The readers were also used to scan PIT tags prior to tag application (so that the tag number could be recorded), and, once inserted, to confirm the active status and number of a PIT tag applied to prior to release of the sturgeon.

Tag Recoveries

PIT Tags

An essential element of the population model used in this program was the positive identification and documentation of both tagged and non-tagged sturgeon in the sample. The PIT tag scanners were used exclusively to determine the presence of a PIT tag. Only verified (scanned) sturgeon were used for analyses in the population model.

External Tags

Other sturgeon tagging projects in the Fraser River, the Columbia River, and elsewhere, had applied external tags to sturgeon. Some of these tags were applied in conjunction with a PIT tag and some were not. Volunteers were trained to record the attachment location, color, type, and all numbers of any external tags encountered on sturgeon.

Biosampling

All sturgeon included in the sampling program were measured for:

1) fork length to the nearest 0.5 cm, measured from tip of snout to fork in tail, measured along the side (lateral line); and
2) girth to the nearest 0.5 cm, measured around the body posterior to the pectoral fins, beneath (not over) the pectoral fins.

The condition of each sturgeon was assessed prior to tagging, and a record was made of the condition of each fish at the time of release (ranking of 1 to 5, with 1 being "excellent" and 5 being a mortality). A small number of captured sturgeon that exhibited visible, serious wounds or deformities, or were assessed to be in some state of poor condition at capture, were scanned and measured, but released without a tag. All visible wounds, scars, and deformities were listed on the data form. In addition, comments were provided to document rare or unique observations regarding individual captures (specific morphological features, deformities, injuries, parasites, markings, etc.).

In 2000, select volunteers were trained to take tissue samples for DNA analyses in response to a request from BC Fisheries. All tissue samples (n = 150) were taken by program volunteers from sturgeon captured in the mainstem Fraser River downstream of the Mission Bridge. These tissue samples and associated sampling data (date, location, fish measurements) were transferred by the program manager to provincial staff (MELP). Results of genetic analyses on these tissue samples are included in the work by Smith et al. (2002).

Fishing Effort

Fishing effort (rod hours) were documented for each angling trip. Volunteers were asked to provide a start and end time for each rod that fished. The total rod hours, total sturgeon catch, and respective location data for the trip were entered into the data base for catch-per-effort analyses. Effort data associated with net fisheries (commercial and First Nation) was not documented. Effort data associated with test fishery operations were recorded by the respective programs and were available for further analyses (i.e., sturgeon catch per date, per set, per standardized net hour, etc.).

Data Management

Data Security and Backup

Volunteers were trained to secure data sheets at the end of each sampling day. Data were then photocopied, either by the volunteer or the program coordinator. The original data were transferred to the program manager for review and entry. Copies of the data sheets were retained by the volunteer for filing. It was important that all volunteers retained a copy of the data that they provided, not only as a data security measure but also for future reference. Following review, the program manager transferred the original (paper) data to a data-entry technician for electronic entry and filing into a master data base. The original (paper) data were filed, and the electronic data backed up on a secure hard drive; data base updates were transferred back to the program manager on a regular basis. Annually, a complete (updated) data base was provided to MOE, typically in February, as per the partnership and program permitting conditions set forth by MOE.

Data Entry

PIT Tag data were entered into an electronic data management program (Microsoft Access©). The data entry program was set up to include multiple checks and confirmations for data correctness and to signal potential data entry error. All PIT tags received from the tag supplier were accompanied with an electronic data base that included a record of each individual PIT tag number. These “purchased” tag data were placed in a master file that was accessed by the data entry program when new (tag release) data was entered. All release data had to have a match in the “purchased” data file for the entry to be valid. In addition, all recapture data entered were checked against release data for validity prior to acceptance. This process included an automated check of recaptured tag numbers against all valid release data (included here were tag release data provided from MOE for sturgeon tagged in the Fraser River watershed during other studies, including the 1995-99 provincial sturgeon study).

Population Estimation

The tagging program and lower Fraser River sturgeon stock have the following characteristics that demarcate the scope of the population estimation methodology and limitations of the estimates:

1) Marks were applied only to sturgeon that can be caught and tagged; thus, estimates are only applicable to that portion of the population. Over 98% of the marks released and recaptured were between 40 cm and 260 cm (fork length) so the analyses concentrated on this range of size classes. Sturgeon smaller or larger were not consistently available with the capture techniques used by this study and are not included in the population estimates.

2) Since the histogram of lengths of sturgeon at release and recapture are not markedly different (Nelson et al. 2004), size selectivity of the gears (net and angling) will not unduly bias population estimates pooled over size classes and gear (Seber 1982).

3) Sturgeon can grow over the life of the study such that fish will recruit into the portion of the size group (population) of interest and the model must take this into account.

4) Sturgeon experience a low rate of natural mortality for sizes greater than 40 cm compared to fish that are less than a year old.

5) While sturgeon can move among watersheds (e.g., Fraser and Columbia rivers), tagging observations indicate that the event is rare. Similarly, movement upstream of Yale (Lady Franklin Rock) into the upper Fraser Canyon and/or upstream of Hells Gate is not expected (to date, no PIT, Floy, or radio-tag sturgeon released in the lower Fraser River have been recovered or detected upstream of Yale, however recovery efforts have been low and infrequent). Thus, we made the assumption that the sturgeon being assessed by this study are essentially a closed population with little immigration or emigration.

6) Marked sturgeon can move to or remain in sections of the Fraser River where the chance of recapturing a marked fish will reflect the different concentrations of marked fish (i.e., the marked fish mix homogeneously throughout the lower Fraser River in the same proportion as unmarked fish, but the concentrations of marked versus unmarked fish in an area of low tagging effort will not necessarily be the same as areas with high tagging effort).

7) Although varying by season, the application of marks tends to be continuous over time rather than episodic (assumed by some mark-recapture experiments; Seber 1982).

8) The number of recaptured marks is sparse on any given day or area which precludes the application of the classical Jolly-Seber open population models (Seber 1982).

In order to address these characteristics for the lower Fraser River white sturgeon stock, we adapted a Bayesian mark-recapture model for closed populations (Gazey and Staley 1986, Gazey 1994) to accommodate growth, movement, unaccounted removal of marks, and non-detection of marks, and to cope with sparse recaptures on any given day or area. The major assumptions required for our Bayesian model are as follows:

1) The population size in the study area does not change substantially over the period of the experiment. Where mortality occurs (e.g., fishing, natural), it can be specified independent of the mark-recapture information. Similarly, sturgeon that

are recruited into the population of interest by growth can be excluded through calculation of a size criterion. Sturgeon are not distributed homogeneously throughout the study area and can move within that area among sampling regions; however, the movement is fully determined by the history of recaptured marks. Immigration and emigration from the study area is inconsequential but movement can be extensive amongst sampling zones and regions over the period of a year.

2) All sturgeon in a stratum (day and sampling region), whether marked or unmarked, have the same probability of being caught. The study area is divided into four discrete sampling regions.

3) Sturgeon do not lose their marks over the period of the study.

4) All marks are reported when sturgeon are recaptured and scanned. If marks are not detected then the rate can be specified independent of mark-recapture information.

Below, we explain the geographical extent of the study area (for the purposes of population estimation), the stratification of the study area and the treatment of the data to account for growth, recruitment, mortality and non-reporting of marks. The procedure constructed to generate the population model is also briefly described and the sensitivity of the estimates to failure of the model assumptions is explored.

<u>Bounding</u>

For the purposes of estimating the lower Fraser River white sturgeon population size, the boundaries of the study area, the sub-area (sampling zone and sampling region) stratification, and the time frame were established as outlined below. The study area consisted of the South Arm and mainstem of the Fraser River from Georgia Strait to Lady Franklin Rock at Yale and included the Harrison River bounded by the confluence of the Fraser River and Harrison Lake, as well as four kilometers up the Pitt River from the confluence area with the Fraser River (Figure 1). Although 14 zones were identified within the study area (based on the physical characteristics of the Fraser River; see Figure 3 and Nelson et al. 1999), data from only eight of these zones were used to generate sturgeon population estimates. Due to a low number or lack of tag releases and/or recaptures, the following zones within the program sampling area (Figure 3) were not included in the population analyses: zones 1N (North Arm), 1M (Middle Arm), 4 (Pitt River and Pitt Lake), 7 (Stave River), 9 (Nicomen Slough) and 11 (Harrison Lake). Table 1 outlines the boundaries of the eight sampling zones within the study area that were used for population analyses (zones S, 3-5, 6, 8, 10, 12, 13, 14).

Since marks were applied in an episodically daily fashion, summary of the mark-recapture data into intervals greater than a day may introduce substantial bias for the population estimates. However, the Bayesian approach to population estimation allows for the calculation of the likelihood of zero recaptures in a given time interval. Thus, all calculations have been conducted at a daily resolution although, for reporting convenience, we use a monthly interval for the data summaries.

Definition of Variables

For the readers convenience, all mathematical notation used in this section are listed below:

Indices

i, j - zone
k - region (consists of one or more zones)
t, v - day

Variables

Δt - time at large
c_{ti} - number of sturgeon examined for marks during day t in zone i
C_{tk} - number of sturgeon examined for marks during day t in the k'th region
d_{ti} - number of sturgeon removed or killed in the recaptures r_{ti}.
g - daily growth coefficient (cm day^{-1})
H - length maximum when t = 1
L - length minimum when t = 1
L_0 - length at release
L_r - length at recapture
L_∞ - asymptotic length
m_{ti} - the number of marks applied during day t in zone i
m^*_{ti} - number of releases available for recapture during day t in zone i
max(t) - length maximum as a function of day t
min(t) - length minimum as a function of day t
M_{tk} - number of marks available for recapture at the start of day t in region k
p_{ij} - proportion of marks released in zone i moving to zone j
Q - instantaneous annual rate of removal
r_{ti} - number of recaptures in the sample c_{ti}
R_{tk} - number recaptures in the sample, C_{tk}
u - proportion of undetected marks
w_{ij} - the total number of recaptures that were released in zone i and captured in zone j over the entire study period

Growth Model

Growth for fish is often characterized by a nonlinear von-Bertalanffy model. However, the usual formulation requires length-at-age data (e.g., Ricker 1975) for parameterization and is not suitable for mark recapture data (length at release, length at recapture and time-at-large). A suitable model can be created from the differential form of the von-Bertalanffy model described by Taylor (1963),

$$(1)\qquad \frac{dL}{dt} = gL_\infty - g \cdot t$$

where g is the growth coefficient, L_∞ is the asymptotic length coefficient and t is time.

The integration of equation (1) with initial conditions that length at release (L_0) equals length at recapture (L_r) when time-at-large is zero (Δt = 0) yields the following:

(2) $$L_r = L_\infty - (L_\infty - L_0) \cdot \exp\{-g \cdot \Delta t\}$$

Estimates of the parameters g and L_∞ were made through nonlinear least squares regression of equation (2).

Data Compilation

The following data are required to be extracted and accumulated from the mark-recapture database in order to generate population estimates:

- m_{ti} - the number of marks released (newly applied marks and marks applied previously) during day t in zone i,
- c_{ti} - the number of sturgeon examined for marks during day t in zone i,
- r_{ti} - the number of recaptures in the sample c_{ti},
- d_{ti} - the number of sturgeon removed or killed of the recaptures r_{ti}, *and*
- w_{ij} - the total number of recaptures that were released in zone i and captured in zone j over the entire study period.

The selection of the marks released (m_{ti}) must meet the following criteria:

1. Only tags applied by this study qualifies for inclusion into the estimate.
2. The time of the tag application has to be greater than or equal to the start-date, i.e., the day t is set to 1 on the start-date and smaller values are not used. Further, the time of the tag application had to be less than or equal to an end-date input by the user. Note that the capture of a previously marked sturgeon during this set time period (i.e., a recapture of a tagged sturgeon that was tagged or previously observed as a recaptured prior to the set time period) which was subsequently released in good health constitutes a release.
3. The length of the sturgeon had to be within a the defined length window, which grows as the study progresses [min*(t)* to max*(t)*] assuming von-Bertalanffy nonlinear growth, i.e.,

   $$\min(t) = \hat{L}_\infty - (\hat{L}_\infty - L)\exp\{-\hat{g} \cdot (t - \tau)\}$$, and
   $$\max(t) = \hat{L}_\infty - (\hat{L}_\infty - H)\exp\{-\hat{g} \cdot (t - \tau)\}$$

   where, L is a length minimum when $t = \tau$, H is a length maximum when $t = \tau$, τ is the time in days from an user input calibration date, $\hat{L}_\infty$ is the asymptotic growth coefficient ("L-infinity") and $\hat{g}$ is the von-Bertalanffy growth coefficient. Parameter estimates $\hat{L}_\infty$ and $\hat{g}$ were obtained using nonlinear regression of equation (2).

A sturgeon is counted as examined (a member of c_{ti}) only if an assessment of whether the fish had been previously tagged took place (i.e., the tag-reader wand was passed over the captured fish) and the size criteria (3, above) was met. A sturgeon was counted as a recapture (r_{ti}) only if it was a member of the sample (c_{ti}) and met a minimum time at large criteria (1 day for this study). A sturgeon was counted as removed (d_{ti}) if it was not returned to the river (e.g., it died) and it was a recapture (r_{ti}).

The number of marks available for recapture adjusted for movement was determined by first estimating the proportion of marks released in zone i moving to recovery zone j (p_{ij}).

Note by definition:

$$\sum_j p_{ij} = 1.$$

Assuming that the movement of marked sturgeon is determined by the recapture history corrected for the sampling intensity then

(3) $$\hat{p}_{ij} = \frac{\dfrac{w_{ij}}{\sum_t c_{tj}}}{\sum_j \dfrac{w_{ij}}{\sum_t c_{tj}}}$$

where w_{ij} is the total number of recaptures that were released in zone i and captured in zone j over the entire study. The maximum number of releases available for recapture during day t in zone j (m^*_{tj}) is then

(4) $$m^*_{tj} = \sum_i \hat{p}_{ij}(m_{ti} - r_{ti}).$$

The usual closed population model assumptions (e.g., Gazey and Staley 1986) may be invalidated by natural mortality, unaccounted fishing mortality, the emigration of sturgeon from the study area and non-detection of a mark when the sturgeon was swiped by the wand (dead battery, non-operating tag , etc.). We incorporated these factors when the data were assembled for a sampling region (see Table 2). Thus, the number of marks available for recapture at the start of day t in region k (M_{tk}) consists of the releases in each of the zones corrected for removals (mortality and emigration) summed over time and into the appropriate region, i.e.,

(5) $$M_{tk} = \sum_{v=1}^{t-1} \exp\left\{\frac{v+1-t}{365} Q\right\} \sum_{j \subset k} (m^*_{tj} - d_{tj})$$

where *Q* is the instantaneous annual rate of removal. The number of fish examined during day *t* in the *k*'th region (C_{tk}) does not require correction (simply sum up the zones in the sampling region), i.e.,

(6) $$C_{tk} = \sum_{j \subset k} c_{tj}$$

The recaptures in the sample, C_{tk}, however, need to be corrected for the proportion of undetected marks (*u*), i.e.,

(7) $$R_{tk} = (1+u)\sum_{j \subset k} r_{tj}$$

The corrected marks available, sample and recaptures (equations 5, 6, and 7) are the input information required Gazey and Staley (1986) to form the population estimates.

Population Model

The estimation of population size was accomplished with a Microsoft Excel© spreadsheet model that consists of macros coded in Visual Basic. The procedure requires the execution of two passes (macros update and estimate). First (execute macro update), the mark-recapture data are assembled by zones (Table 1) under the selection criteria of the start-date, end-date, growth cohort calibration date (the date that the minimum and maximum length specifications apply), minimum time-at-large (days), minimum length (cm), maximum length (cm), asymptotic length (cm), and the growth coefficient specified by the user. For the second pass (execute macro estimate), the user must specify the zones to be included in the estimate (i.e., zones aggregated into a sampling region), annual instantaneous removal rate, the proportion of undetected marks and the confidence interval percentage desired for the output. The model then assembles the adjusted mark-recapture data (equations 5, 6 and 7) and follows Gazey and Staley (1986) using the replacement model to compute the population estimates. Output includes the last 200 posterior distributions, the Bayesian mean, standard deviation, median, mode (which is the maximum likelihood estimate), symmetric confidence interval and the highest probability density (HPD) interval.

Population estimates were generated for the four sampling regions defined in Table 2 using a start-date of 17 January 2005, an end-date of 17 December 2006, a growth cohortratiibration date of 1 January 2006, minimum time-at-large of one day, a minimum length of 40 cm, a maximum length of 260 cm, asymptotic length of 412.8 cm and a growth coefficient of 6.388E-05 (see **RESULTS** for details), an annual instantaneous removal rate (representing natural mortality, unobserved removals and emigration) of 0.1 and a undetected mark rate of 1%. Note that these regional estimates are made assuming that the population size is constant over the period of tag application. The true population size likely has seasonal cycles in any one sampling region; thus, the regional estimates over the experimental period are somewhat analogous to a mean estimate. However, the total population size in the study area is expected to be stable. The total population estimate for the study area was obtained by summing the regional estimates. The confidence interval for the total study area estimate was calculated invoking a normal distribution under the central limit theorem with a variance equal to the sum of the variances for the sampling regions.

Estimates were made by the 20 cm size intervals calibrated at 1 January 2006 in an attempt to identify the source on any change in the population size. Population estimates by sampling region and size category were not attempted because of few recaptures. The lack of stratification and the uncertainty introduced by large measurement errors in the growth increment resulted in some bias in the estimation of population size. Also, some size categories (in particular, the 40–59 cm interval) produced highly skewed posterior distributions generated by sparse recaptures. The mean point estimate becomes unstable under these circumstances. In order to correct bias and control stability, the maximum likelihood estimates (MLE's) by size category were standardized to the Bayesian mean estimate derived without size categories.

Removal Estimate

The von-Bertalanffy growth model allows us to calculate the time required to grow from a reference length (L_0) to a mid-point of size class i (L_i) by solving equation (2) for time-at-large, i.e.,

(8) $$\Delta t_i = \frac{1}{g} \cdot \left[\ln(L_\infty - L_o) - \ln(L_\infty - L_i) \right]$$

A simple "catch curve" population decay model (Ricker 1975) can be constructed from the size class estimates using time at large instead of the usual age as follows:

(9) $$\ln(N_i) = \ln(N_o) - Q \cdot \Delta t_i$$

where N_i is the abundance estimate of size class i and N_o is the abundance for the reference size class. Estimates of the instantaneous rate of removal (Q) can be obtained using simple least squares regression. Since the "catch curve" model assumes that the size composition is stable over long periods of time (i.e., recruitment into the population and mortality for all size classes are constant), the removal rate estimate should be regarded as crude.

Sensitivity

The population model made allowance for sturgeon movement within the study area and growth, and these statistics were substantiated using the mark-recapture data. Some confirmation was also possible for the removal rate, as indicated above. In contrast, the specification of undetected mark (e.g., wand or tag malfunction) rate was made without quantitative substantiation. The sensitivity of removal and undetected rates on the population estimates was explored by generating simultaneous estimates using removal rate values ranging from 0.0 to 0.2 and undetected mark rates ranging from 0% to 2%, values which we feel are reasonable based on our field experience. Concerns related to the potential concentration of sampling effort and recoveries in portions of the study area were assessed by compiling annual statistics on the number of sturgeon sampled and number of recoveries for each km unit in the study area. The km units were then sorted from highest to lowest and the percent of the total number samples or recoveries in a given year (represented by highest 1, 2, 3, … *n* km units) was determine and plotted. Curves closer to the y-axis indicate that fewer sampling locations (km units) comprise a larger portion of the total number of sturgeon sampled or recaptured than curves farther from the y-axis.

RESULTS

Population Estimates

<u>Growth</u>

We determined von-Bertalanffy growth model parameter estimates and compared a linear daily model (Table 3). The von-Bertalanffy model fit the data much better than a simple linear model (R2 = 0.957 compared to R2 = 0.706, respectively). Comparisons of among-size classes within our data set (see Nelson et al. 2004) were examined and we determined change in length over time and rate of change over time. The asymptotic length estimate of 412.8 cm is well beyond the size of any fish sampled during this study (few exceeded 220 cm and the largest observed was 343 cm); however, larger sturgeons have been observed (Scott and Crossman 1973) and this falls within the range of expected maximum sizes observed historically.

The mark-recapture data were extracted by zone from the database using a start-date of 17 January 2005 and end date of 17 December 2006. The minimum time-at-large was one day; lengths were a minimum of 40 cm and a maximum of 260 cm. These data were calibrated at 1 January 2006 and a von-Bertalanffy asymptotic length of 412.8 cm and growth constant of 6.336E-05 was determined. Table 4 lists the number of sturgeon examined for marks and the number of recaptures observed, by month and zone. The total number of sturgeon examined (scanned) for the presence of a PIT tag (from all sampling zones, from 17 January 2005 through 17 December 2006) was 18,368; the number of PIT tags observed (recaptured sturgeon) from the group of tags applied (or previously recaptured) during this same time period was 2990, for an overall mark rate of 16.3%. The total number of PIT tagged sturgeon (from this study) recaptured during this 24-month period from all Program release years (since October 1999) was 7360, for an overall tag rate (number of PIT tags from this study observed in the total sample during this the 24-month time period) of 40.1%.

Table 5 provides the summary of recaptures by release and recapture zone along with the associated sample size (sturgeon examined) by zone. The subsequent migration proportions (equation 3) are displayed in Table 6. The releases, adjusted for movement between zones (equation 4) by zone and month, are given in Table 7. These data show that the greatest fidelity to an area was the most upstream location (zone 14, Hope to Yale) while the adjacent zones 8 and 12 (Mission to Agassiz) had the most movement based on their proportion (corrected) of sturgeon recaptured by zone of release (recapture corrected for sampling intensity; see equation 3). Note that the total numbers of marked sturgeon releases available for recapture by zone and month (Table 7; see equation 4) were relatively similar among areas (average 1743 fish), zone S (819 fish) and zone 14 (624 fish) being the exceptions.

The numbers of marks available (equation 5), sturgeon examined (equation 6), and recaptures (equation 7), were compiled by specific sampling region, assuming 0.1 removal and 1% undetected mark rate. The subsequent population estimates, by sampling region, are presented in Table 8. The population estimate for the entire study area as of 1 January 2006 (the mid-point of the reported study period) was 46,957 (95% HPD range 44,719-49,195). Figure 4 illustrates the mean population estimates of white sturgeon by sampling region. The sampling region with the lowest estimated number of white sturgeon was region D (Hope to Yale) at 3,599 sturgeon while the sampling region with the highest estimated number of sturgeon was region C (Mission to Hope) at 24,668.

The sturgeon population estimates by 20-cm size category as of 1 January 2006 are listed in Table 9; these estimates are calculated as mean estimates for the population over the duration of study period (17 January 2005 through 17 December 2006). As noted previously, maximum likelihood estimates (MLEs), by size class, were used and scaled to the overall mean estimate for the study area. Therefore, the population estimates and confidence intervals are also expressed as a percent of the MLE. Figure 5 charts the adjusted MLE estimates by size category with the associated 95% HPD intervals presented in Table 9. Note that the size distribution is skewed with the modal size class being 80-99 cm.

<u>Removal Estimate</u>

Explanations regarding the removal rate (Q) estimate used in the population analyses, and testing for sensitivity of the population estimates to undetected marks and removals (natural mortality, unobserved mortalities and removals, and emigration from the study area) are explored and detailed in Nelson et al. (2004).

<u>Distribution of Effort</u>

Sampling effort and subsequent recapture of tagged sturgeon are more widely distributed across the study area in each successive year of the assessment program. In 2000 and 2001, the 20 most-productive single-kilometer units (see Figure 6) comprised more than 80% of the total number of sturgeon sampled and tag recoveries. In 2005 and 2006, samples from more than 35 single-kilometer units were required to account for 80% of the samples and recoveries. If the location of samples (both total samples and recaptures) provided by program volunteers became more concentrated in a low number of productive locations, we would have expected to see the opposite result. The likely explanation for the trends observed is that the geographic distribution of sampling effort (and respective recapture events) within the study area has increased over the course of the program. This measurable expansion of data collection across the study area is likely a result of: 1) encouragement (by program managers) to volunteers to make dedicated efforts to distribute and expand the locations of sampling efforts; and 2) the addition of new participants to the program that apply sampling efforts in a variety of locations. The distribution of recoveries has increased for similar reasons, as has the increased potential for recoveries from more areas, as the number of tagged sturgeon in the population increases.

DISCUSSION

Sampling Effort for Mark-Recapture Population Estimates

Appendix B presents a summary of sampling levels, including tagging and recapture levels, by month and year, since the start of the Lower Fraser River White Sturgeon Monitoring and Assessment Program in October 1999 through 31 December 2006. Since the inception of the current sampling program, a total of 47,044 sturgeon have been sampled for the presence of a PIT tag and 30,409 have been tagged with a PIT tag (in the "head" location) and released. A total of 11,898 recapture events have been documented, the slight majority of which (50.9%) are repeat recapture events of the same individual fish (recaptured more than once; Table 10). In addition, 4737 sturgeon that were not recaptures were sampled (examined for the presence of a PIT tag and measured), but a tag was not applied (the high majority of these fish were sturgeon that were released alive without a tag due to limitations of tag availability; a smaller number of these fish were mortalities from either net interceptions or other causes).

<u>Sources of Sturgeon Samples</u>

Although there are several sources that provide sturgeon samples for the FRSCS program, three sources have provided over 98% of samples over the life of the program: angling 81.6%; First Nations gill net 9.5%; and Albion Test Fishery 7.5% (Figure 7). An additional 1.4% of the total sample has been provided through mortalities, commercial net fisheries, and enforcement (illegal retention/poaching) incidents. The majority of sampled mortalities were sturgeon that were found dead in the Fraser River (on the beach or floating) and were subsequently sampled by program volunteers; note that tag data from all tagged mortalities recovered were adjusted in the core data base so that these marked fish were not considered for subsequent population analyses (see **FIELD AND ANALYTICAL METHODS**).

Recaptures of Tagged Sturgeon

Recapture data of tagged sturgeon provided positive determination of both direction and distance of movements for individual sturgeon, and in many cases multiple recapture events over time (years) provided patterns of movement and migration. Movements in relation to both size category and time of year (season) were explored and incorporated in the analytical processes of the program, as were the spatial distribution of samples over the course of the program.

Mark Rates

Calculated mark rates for the current program (based on the number of sturgeon sampled and the number of program-applied PIT tags recaptured) are provided (Appendix B) by month and year. Mark rates have tended to increase proportionally to the increased number of tags applied in the population; mark rates in the summer and fall of 2006 exceeded 40%. A measured drop in mark rates in winter samples (December through February) has been observed each year; although sample sizes and sampling locations are reduced from summer and fall sampling efforts, the winter mark rates suggest a moderate rate of population segregation between summer-fall (high levels of sampling/tag applications) and winter periods. From late December through February, white sturgeon in the lower Fraser River exhibit “overwintering” behavior (concentrations of sturgeon in known locations of moderate-deep water levels and low flows; lethargic, reduced feeding and feeding aggression; Nelson et al. 2004).

Recaptures from Previous Studies

From 1995-1999 approximately 850 PIT tags were applied to white sturgeon downstream of Hell’s Gate (and upstream of the Mission Bridge) under the provincial Fraser River White Sturgeon Monitoring Program (RL&L 2000). In this study, PIT tags were applied above the lateral line near the base of the dorsal fin. Under the current FRSCS study, “dorsal” PIT tags are occasionally detected and the data recorded. Through December 2006, 280 unique dorsal PIT tags have been detected, and in most cases a new PIT tag was applied to these sturgeon in the “head” location prior to release. Several individual sturgeon that were originally tagged during the 1995-99 study and subsequently recaptured during the 2000-2006 FRSCS program have provided valuable information regarding longer-term movement and growth.

Population Estimates

A Bayesian mark-recapture model for closed populations (Gazey and Staley 1986) was adapted to incorporate growth, movement, unaccounted removal of marks (natural mortality, unobserved mortalities and removals, and emigration from the study area) and non-detection of marks when a sturgeon was assessed for a PIT tag (e.g., scanner error/battery failure, observer error, non-operating tag). The Bayesian estimation methodology allowed for very sparse recaptures; thus, daily increments to the number of marked sturgeon in the population and daily sampling for recaptures were accommodated. The population of white sturgeon in the lower Fraser River between Yale and the Strait of Georgia was estimated to be 46,957 fish in the size range from 40 cm to 260 cm; this encompassed the period between 17 January 2005 and 17

December 2006. This estimate had a 95% confidence interval of ± 2,238 sturgeon with a coefficient of variation of 3.5%.
The exceptional precision generated by this study is remarkable. However, the accuracy of the estimate is conditional on the rate of removals and the unevaluated rate of undetected marks. The upper limit of the removal rate (0.2) used by the sensitivity analysis was purposely chosen to be extreme given the very long life of sturgeon and the relative rarity of tags recovered in other watersheds (Nelson et al. 2004). This rate would imply about 18% of the population is killed each year by natural mortality, unreported angling mortality, mortality from commercial or First Nation gill nets (Robichaud et al. 2006), or poaching. The preliminary removal rate estimate of 0.13 from the size class estimates provides some credibility to the recommended value of 0.10 and the upper bound of 0.20. Similarly, the upper limit of undetected marks (2%) is thought to be extreme because of frequent checking of scanner operation, the high competence level of trained volunteers, and the quality assurance components of the program. Alternatively, it is unreasonable to assume that no removals occurred or that every mark was detected.

Population estimates presented may not include representation from zones within the study area that did not produce enough tag release and/or recapture data (see **FIELD AND ANALYTICAL METHODS**, Bounding). The entire North Arm (and adjacent Middle Arm south of Lulu Island), the Pitt River and Pitt Lake, and Harrison Lake were not included in the population estimates. White sturgeon are known to inhabit all of these areas that were not represented in the population analyses, at least seasonally; mixing of sturgeon from these areas into the mainstem Fraser zones used to estimate the population is unknown.

Comparison of Population Estimates (1999-2006)

Based on the high precision of mean population estimates for lower Fraser River white sturgeon generated by this program, comparisons between and among estimates provide reliable indications of population trends over the term of the program. Figure 8 compares the population estimate as of 1 January 2006 (46,957) with previous annual (independent) population estimates produced by this assessment program. The 2004, 2005, and 2006 population estimates sturgeon from 220-260 cm FL (see footnotes, Figure 8), whereas previous estimates did not include fish over 220 cm FL (due to an insufficient number of recaptured tags in the higher size categories).

A gradual population increase was observed during the first four years of the program, from a low of 47,431 in 1999 to a high of 62,611 in 2003 (Figure 8). Since 2003, population estimates generated by the program indicate a gradual population decrease (10.1% in 2004, 12.9% in 2005, and 4.2% in 2006; Table 11). The 2006 population estimate is the lowest estimate since the inception of the assessment program. Comparisons of recent population estimates with the 2003 (peak) estimate indicate a 21.7% population decrease by 2005 and a 25.0% decrease by 2006 (Table 11). A comparison of upper confidence level (HPD, Table 8) associated with the 2006 estimate and the lower confidence level associated with the 2003 estimate (Nelson et

al. 2004) indicate that the population decrease is significant (see presentation of confidence ranges in Figure 8).
A comparison of annual population estimates by 20-cm size categories for 2004, 2005, and 2006 (Figure 9) illustrates where changes are occurring for specific size/age groups within the population. The 2006 abundance estimates by size category suggest that significant reductions have occurred in the smallest size categories (40-59 cm and 60-89 cm) since 2004, which suggests reduced levels of juvenile recruitment into the population as compared to recruitment levels before 2004. Note also for 2006 that increases in abundance have occurred in all categories above 100 cm (this suggests survival and growth of individual sturgeon over time into higher size categories, thus measurable increases in abundance in these size categories over time).

To further explore the suggestion of recent population decreases for smaller (younger) sturgeon in recent years, we compared the proportional frequency of sturgeon under 130 cm FL captured by angling only (Figure 10) and from the Albion Test Fishery (Figure 11); capture (gear) source separation was important in these analyses due to possible size-selective capture bias associated with the different gear types. A comparison of annual frequencies of sampled sturgeon, by 10-cm size groups, for all sturgeon captured (under 130 cm FL) since 2000, showed a decreasing trend over time for both capture sources (angling and Albion Test Fishery). In 2006, the sample of sturgeon below 130 cm FL captured by angling displayed reduced proportions of fish less than 80 cm FL, and increased proportions over 80 cm FL, as compared with a respective sample from in 2000 (Figure 10). Decreases were most pronounced for the 50-60 cm group (-6.3%) and 60-70 cm group (-6.4%). Similarly, a comparison of the frequency sturgeon (below 130 cm FL) sampled by the Albion Test Fishery in 2006 and 2000 (Figure 11) displays a reduction in the proportions of sturgeon less than 90 cm FL, with the greatest change occurring in the 70-80 cm size group (-14.1%). Increases in the proportions of all size groups over 90 cm FL from both gear types suggests survival of individual sturgeon and growth into higher size categories over time.

The fundamental results of the proportional analyses of juvenile sturgeon abundance, over time, support results of the size-based population analyses (see Figure 9); there has been a general decrease in the abundance, and proportion te sxite sturgeon less than 100 cm, over the course of the program (since 2000). In addition, we have strong indications that the majority of lower Fraser River white sturgeon currently over 100 cm have survived and have continued to grow over the course of the monitoring program.

Estimates of Mature White Sturgeon

Reliable estimates of the number of mature white sturgeon in a given population would provide respective stock-specific recovery teams with valuable stock monitoring and management information. In addition, if reliable data regarding sex ratios were available, especially for the mature component of the population, stock managers would be another step closer toward effective recovery management. Finally, if reliable estimates/information regarding fecundity, spawning periodicity/frequency, and survival rates at early life stages (egg, larvae, young-of-year) could be provided, potential

recruitment could be estimated and subsequently monitored. Unfortunately, very little of this information is currently available for lower Fraser River white sturgeon.
The concept of achieving a target number of "mature" adults (or females) in given populations of white sturgeon is put forth in the *Fraser River White Sturgeon Conservation Plan* (Fraser River White Sturgeon Working Group 2005) and the national *Recovery Strategy for White Sturgeon* (National Recovery Team for White Sturgeon 2007). Based on the size-grouped population estimates produced by the FRSCS program, and the high precision of these estimates, we can provide reliable estimates of the number of white sturgeon in the size classes that should be mature (for females, above 160 cm FL; males may mature at smaller sizes; RL&L 2000). From the size-stratified population estimates presented in Table 9, we estimate a mean population of white sturgeon from 160-259 cm FL to be 7616. In addition, we are assured that sturgeon greater than 259 cm FL currently exist in the lower Fraser population. Since 1999 through 2006, the FRSCS program has sampled a total of 58 individual sturgeon that were greater than 259 cm FL; if we expand this known number by a standard recapture rate (30%) we get an estimated total of 174 sturgeon over 259 cm FL. The sum of the mean estimate of sturgeon 160-259 cm (7616) and expanded estimate of sturgeon greater than 259 cm (174) is our current total estimate of the number of potentially mature sturgeon in the population (7790); the confidence range of this mean estimate (95% HPD values) is 6600-9400 sturgeon over 160 cm FL.

Standing sex ratios of white sturgeon in the lower Fraser River, for all size categories, are currently unknown. Given a sex ratio of 50:50, the mean estimate of the number of females over 160 cm FL would be 3895, based on the total mean estimate (7790), and would range from approximately 3317 to 4720 (95% HPD estimates). Spawning periodicity (frequency) is also not known, and may be effected by size/age, number of previous spawning events, physical condition (food intake, injuries, etc.), and various environmental conditions. Given an average female spawning frequency of every four years, a 50:50 sex ratio would result in an average of 974 females (over 160 cm FL) spawning in the lower Fraser River every year; if the average spawning frequency was eight years, we estimate an average of 487 females spawning per year. Skewed sex ratios would increase or decrease these estimates proportionately.

Sturgeon Movement and Migration

Distances moved between release and recapture locations, by river kilometer, and movement between both sampling zones and sampling regions, were considered by the population model for each valid recapture event. In addition to providing estimates of the probability of recapture between zones (necessary for the population analyses), these data provided additional insights regarding the inter- and intra-annual migrations of white sturgeon in the lower Fraser River.

Nelson et al. (2004) suggests that intra-annual life-history events may result in substantial, directed movements of white sturgeon within the lower Fraser River study area. Some concentrations of sturgeon by size/age may also occur, especially in the extreme lower (juvenile sturgeon) and upper (mature/spawning sturgeon) study regions.

The mark-recapture data from this study (and other fishery monitoring and anecdotal sources) suggest that, in the lower river, annual downstream migrations of sturgeon occur in the spring from upstream overwintering areas, and that these migrations coincide with the in-migration and spawning of Pacific eulachon in the lower Fraser River and estuary (sampling region A). Eulachon are a preferred prey item of Fraser River white sturgeon; annual sturgeon migrations into the areas where eulachon concentrate and spawn is well documented in the literature (Northcote 1974).

Patterns of annual sturgeon movements and migrations within the lower Fraser River can be illustrated through an analysis of the daily catch of sturgeon from the Albion test fishery vessel, a commercial gill netter that makes two sets in generally the same location in the Fraser mainstem (river kilometer 58) on a daily basis from 1 April through 30 November. The change in the number of sturgeon captured should reflect, as an index, the change in abundance of sturgeon in this section of the river over short periods of time. When daily sturgeon captures are summed by month (Figure 12), a bimodal pattern appears; this pattern has remained consistent between the seven years of sampling by the FRSCS monitoring and assessment program. Note (Figure 12) that the number of sturgeon captured in the Albion test fishery peaks in May during the peak of eulachon abundance in the lower Fraser, and then decreases in the mid-summer. The catch of sturgeon then builds in late August, September, and into October during the period of major in-migration of salmon into the Fraser. Salmon and salmon roe (especially pink and chum salmon roe, which is the most readily available salmon in the mainstem of the Fraser) is likely an important food source for white sturgeon.

The Albion test fishery location is situated upstream of the highest concentrations of eulachon spawning, and downstream of the high majority of salmonid spawning (including pink and chum salmon). Thus, because changes in the number of sturgeon caught in the test fishery likely reflect the passage (migration) of sturgeon; there appears to be a downstream migration in the spring, and an upstream migration in the late summer and fall. These observations are supported by intra-annual tag and recapture data. In both 2001, 2003, and 2005 (years of pink salmon returns), sturgeon catch at the Albion test fishery increased earlier in August and September as compared to non-pink years (2000, 2002, and 2004). In 2003, a high number of pink salmon returned to the Fraser River (estimates over 40 million); this year saw a marked increase of sturgeon captured in the Albion test fishery in September through November. It is likely that this observed abundance of sturgeon migrating in the Fraser River was in response to the abundance of food.

Recaptures of individual PIT-tagged sturgeon during this study confirm that movements and migrations occur throughout the entire study area. Individual sturgeon, initially tagged in the upper Fraser Canyon near Yale, were recaptured in the lower Fraser estuary, with some of these individuals being subsequently recaptured in the middle Fraser Valley and/or back in the upper Fraser Canyon. Migrations of up to 164 kms (downstream migration) and 166 kms (upstream migration) have been documented. Sturgeon tagged in the Harrison River (downstream of Harrison Lake) were recaptured in the mainstem Fraser River, and Fraser mainstem releases were recaptured in the

Harrison River. In general, white sturgeon migrate throughout the entire lower Fraser River and utilize a diversity of rearing, feeding, spawning, and overwintering habitats.

Fraser River Recaptures of White Sturgeon Tagged in the Columbia River

This study has confirmed that white sturgeon do indeed travel between the Fraser River and the Columbia River by way of marine waters. Two tagged white sturgeon captured during this study were confirmed to have originally been tagged and released in the Columbia River near Astoria, Oregon. The tags on both of these recaptured sturgeon were external "loop" tags, attached at the base of the dorsal fin. Tag numbers and release information were confirmed by staff at the Washington Department of Fish and Wildlife (Battlefield, WA). Both sturgeon were released in the mainstem Columbia River upstream of the bridge at Astoria, Oregon (release dates were 9 May 1997 and 25 May 1999). Both fish were recaptured in the mainstem Fraser River upstream of Mission, BC. Time abroad from release to recapture was similar (65 months and 60 months, respectively).

It is possible that these sturgeon were spawned in the Fraser River, and migrated south to the Columbia when they were very young, perhaps 3-8 years old, where they resided before returning to the Fraser. It is also possible that these sturgeon were spawned in the Columbia River, and that they left the Columbia (likely in search of food) and eventually migrated into the Fraser River. Based on their lengths (112 and 120 cm, respectively), both sturgeon were likely 12-18 years old when they were recaptured.

Length and Growth Analyses

Sturgeon Age at Length

Age-at-length data were collected during the 1995-99 Fraser River sturgeon studies conducted by the Province of BC. A total of 1075 sturgeon with known fork lengths (cm) were aged (age structure used was the pectoral fin ray). These data exhibit high variance of estimated age for similar sizes of sturgeon. For example, fish from 50-80 cm in length ranged in age from 4-17 years old (with over 90% being 5-12 years old). Some of this variance could be attributed to sex-specific growth rate differences. Other reasons for the age-at-length variance is likely attributable to the different areas/stock groups from which these sturgeon were sampled and respective growth-rate differences between these locations/stocks (the data includes samples from the upper Fraser and Nechako watersheds where growth rates may vary from those in the lower Fraser). We have plotted these data as average lengths at age (increments) in Figure 13. Using this curve, it appears that the bulk of sturgeon sampled below 150 cm FL were less than 25 years old, and that fish below 170 cm FL were less than 50 years old.

Growth Analyses

Fork length data for individual recaptured (tagged) sturgeon were analysed to determine daily growth rates, based on the number of days at large between the release and subsequent recapture events. Daily growth rates were expanded to provide estimates of annual growth, and these estimates were pooled and averaged by size groups for comparative purposes. A comparison of annual growth rates of white sturgeon early in the monitoring program (averaged for 2000-2001) with more-recent growth rates (averaged for 2005-2006), by 20-cm size groups, suggests that, for all size groups of sturgeon from 40-180 cm, growth was higher during the first 2 years of the program as compared to the more-recent rates (Figure 14). The greatest change in this comparative analysis was for sturgeon 80-100 cm FL; in 2000-2001, fish in this size range grew an average of 5.79 cm/year, whereas in 2005-2006, average growth was reduced to 4.36 cm/year, a decrease of 1.43 cm/year (a growth decrease of 24.7% for this size group).

The reductions in annual growth rates may reflect natural growth fluctuations for the population, and may indicate that growth rates in 2000-2001 were good or above average. However, the reductions may also indicate reduced and/or below average growth for these size groups of sturgeon in recent years (2005-2006). Because sturgeon growth is in part a function of food intake, we can look for changes in the abundance/availability of major food sources over the period from 2000-2006. Whereas salmon escapements/abundance has fluctuated over this period (and pink salmon, which is a major food source, is only available on odd years), the estimated abundance or Pacific eulachon, which is a key food source for lower Fraser River white sturgeon, has declined substantially in the lower Fraser River over this period. In addition to population monitoring and assessment, is important to continue to closely monitor annual growth rates for lower Fraser River white sturgeon, and to track growth against changes in the abundance of important food sources.

ACKNOWLEDGEMENTS

The novel and reliable information that has been produced by this program is a direct result of the energy, commitment, and dedication of program volunteers and sponsors. The level of in-kind contributions to the program from program volunteers, however measured (in hours, equipment, dollars, or numbers of individuals), is second-to-none for recent BC-based fisheries research programs. Program volunteers are true stewards of the resource that is Fraser River white sturgeon. The level of program involvement by volunteers and the significant support and interest shown by both program sponsors and the public at large is a testimony to the broad community commitment toward stock recovery of lower Fraser River white sturgeon.

All great endeavors have a great leader, and the Fraser River Sturgeon Conservation Society is no exception. Rick Hansen was a founding member of the Society in 1997, and has served as chairman of the Society since its inception. Rick has been responsible for the visions, pathways to success, and orchestration of key players and elements that have led to the Society's accomplishments.

All great field studies have a great field program coordinator. Since 1999, Jim Rissling has provided training, quality assurance, and program management for both the monitoring and assessment program and the First Nations stewardship program.

Financial sponsorship was provided through partnership arrangements with provincial, federal, and non-government foundations and organizations, plus private donations:

Canadian National Sportsmen’s Shows
Endswell Foundation
Environment Canada – Habitat Stewardship Program for Species at Risk
Fisheries and Oceans Canada
Fisheries Renewal BC
Fraser Valley Angling Guides Association
Habitat Conservation Trust Fund
LGL Limited environmental research associates
Ministry of Environment
Nature Trust of BC
Rudy and Patricia North Foundation
Vancouver Foundation
Vancouver Port Authorities
Willow Grove Foundation

The FRSCS Board of Directors of would like to thank all program funders, sponsors, volunteers, and organizations for their efforts, contributions, and dedicated support of Fraser River white sturgeon.

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TABLES

Table 1. Sampling zones used for population estimation of white sturgeon, 2005-2006.

Zone	River Km	From	To
S*	1-26	Georgia Strait	Eastern Annacis Island
3, 5**	26-56.5 & P1-P4	Eastern Annacis Island	Albion Ferry Crossing
6	56.5-79	Albion Ferry Crossing	Mission Bridge
8	79-94	Mission Bridge	Mouth of Sumas River
10	H0-H19	Confluence Fraser River	Outlet of Harrison Lake
12	94-123	Mouth of Sumas River	Agassiz Bridge
13	123-159	Agassiz Bridge	Hwy 1 Bridge (Hope)
14	159-187	Hwy 1 Bridge (Hope)	Lady Franklin Rock (Yale)

* Zone S is the Main (South) Arm including Canoe Pass; from Figure 3 this is zone 2S and zone 2C
** Zone 5 includes the lower 4 kms of the Pitt River, from the Fraser mainstem to the Hwy 7 Bridge

Table 2. Sampling regions used for population estimates of white sturgeon, 2005-2006.

Region	Zones	Description
A	S	Georgia Strait to Eastern Annacis Island (South Arm of Fraser)
B	3-5, 6	Eastern Annacis Island to Mission Bridge
C	8, 10, 12, 13	Mission Bridge to Hope including the Harrison River
D	14	Hwy 1 Bridge (Hope) to Lady Franklin Rock (Yale)

Table 3. Parameter estimates for linear and non-linear sturgeon growth models (2005-2006).

Parameter	Estimate	Std Error	R^2
Linear			0.706
Daily Increment	1.935E-02	2.496E-04	
Non-Linear von-Bertalanffy			0.957
L_∞	412.8	34.3	
g	6.338E-05	7.090E-06	

Table 4. Numbers of sturgeon examined for marks (Catch), and number of recaptures (Rec)[1], by month and sampling zone, 2005-2006.

	Zone S		Zone 3-5		Zone 6		Zone 8		Zone 10		Zone 12		Zone 13		Zone 14		Total	
Month	Catch	Rec	Catch	Rec	Catch	Rec	Catch	Rec	Catch	Rec	Catch	Rec	Catch	Rec	Catch	Rec	Catch	Rec
Jan-05	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	18	0
Feb-05	0	0	0	0	202	3	1	0	0	0	17	0	0	0	0	0	220	3
Mar-05	7	0	1	0	219	7	13	0	4	0	33	0	10	0	0	0	287	7
Apr-05	54	0	108	2	430	19	88	0	17	0	72	2	48	1	0	0	817	24
May-05	50	3	17	0	48	1	60	5	0	0	199	21	60	0	35	0	469	30
Jun-05	115	8	1	0	63	6	163	6	1	0	281	18	47	4	46	3	717	45
Jul-05	75	7	3	0	57	3	160	7	0	0	322	26	49	6	24	1	690	50
Aug-05	59	4	61	4	102	9	329	26	67	7	505	58	91	5	37	3	1,251	116
Sep-05	10	2	76	5	276	12	762	60	115	12	501	52	43	2	10	1	1,793	146
Oct-05	0	0	0	0	278	20	807	70	549	125	397	59	16	0	0	0	2,047	274
Nov-05	0	0	1	0	173	17	551	46	141	43	187	26	0	0	0	0	1,053	132
Dec-05	0	0	0	0	215	10	60	3	0	0	8	5	0	0	0	0	283	18
Jan-06	0	0	0	0	76	6	0	0	0	0	5	2	0	0	0	0	81	8
Feb-06	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0
Mar-06	32	2	1	0	42	3	5	1	0	0	33	7	0	0	0	0	113	13
Apr-06	35	1	127	10	555	75	35	5	1	0	80	28	35	8	20	2	888	129
May-06	9	1	54	22	154	24	52	6	1	1	150	46	17	4	12	1	449	105
Jun-06	30	7	6	0	16	4	8	1	0	0	156	35	15	0	39	6	270	53
Jul-06	37	2	0	0	12	2	54	13	0	0	183	54	85	21	125	12	496	104
Aug-06	29	4	11	1	33	8	228	43	13	5	312	85	148	31	11	0	785	177
Sep-06	22	12	15	3	124	19	657	150	92	36	304	105	49	16	9	0	1,272	341
Oct-06	2	0	1	0	419	109	1106	261	254	116	709	242	21	4	1	1	2,513	733
Nov-06	0	0	0	0	297	51	905	204	54	20	543	185	31	10	0	0	1,830	470
Dec-06	0	0	0	0	11	3	0	0	5	5	8	4	0	0	0	0	24	12
Totals	566	53	483	47	3,820	411	6,044	907	1,314	370	5,007	1,060	765	112	369	30	18,368	2,990

[1] Recaptures listed in this table are recaptured marks that were sampled or applied during the sampling period of Jan-2005-Dec 2006.

Table 5. Number of sturgeon recaptured and examined for a mark by sampling zone of release and recapture, 2005-2006.

Release Zone	Recapture Zone								Total
	Zone S	Zone 3-5	Zone 6	Zone 8	Zone 10	Zone 12	Zone 13	Zone 14	
Zone S	39	2	6	14	0	8	0	1	70
Zone 3-5	2	7	25	27	1	4	0	0	66
Zone 6	9	30	266	135	5	64	5	0	514
Zone 8	1	2	63	495	14	152	6	1	734
Zone 10	0	0	6	17	235	113	8	0	379
Zone 12	1	4	38	192	109	680	42	6	1,072
Zone 13	0	2	6	25	6	37	50	3	129
Zone 14	1	0	1	2	0	2	1	19	26
Number Recaptured	53	47	411	907	370	1060	112	30	2,990
Number Examined	566	483	3,820	6,044	1,314	5,007	765	369	18,368

Table 6. Proportion (corrected) of sturgeon recaptured by sampling zone of release, 2005-2006 (recapture corrected for sampling intensity; see equation 3).

Release Zone	Recapture Zone								Total
	Zone S	Zone 3-5	Zone 6	Zone 8	Zone 10	Zone 12	Zone 13	Zone 14	
Zone S	0.848	0.051	0.019	0.029	0.000	0.020	0.000	0.033	1.000
Zone 3-5	0.115	0.474	0.214	0.146	0.025	0.026	0.000	0.000	1.000
Zone 6	0.082	0.322	0.361	0.116	0.020	0.066	0.034	0.000	1.000
Zone 8	0.011	0.027	0.106	0.525	0.068	0.195	0.050	0.017	1.000
Zone 10	0.000	0.000	0.007	0.013	0.827	0.104	0.048	0.000	1.000
Zone 12	0.005	0.024	0.029	0.093	0.243	0.397	0.161	0.048	1.000
Zone 13	0.000	0.043	0.016	0.043	0.048	0.078	0.686	0.085	1.000
Zone 14	0.032	0.000	0.005	0.006	0.000	0.007	0.024	0.927	1.000

Table 7. Numbers of marked sturgeon releases available for recapture by sampling zone and month 2005-2006 (see equation 4).

Month	Zone S	Zone 3-5	Zone 6	Zone 8	Zone 10	Zone 12	Zone 13	Zone 14	Total
Jan-05	1	6	6	2	0	1	1	0	18
Feb-05	16	64	72	25	8	20	10	1	217
Mar-05	24	70	79	35	17	31	20	3	279
Apr-05	91	187	180	117	49	80	62	11	777
May-05	48	33	32	54	45	80	71	47	410
Jun-05	100	36	48	118	76	141	81	62	661
Jul-05	62	34	46	117	85	154	86	44	628
Aug-05	65	77	84	193	169	227	140	64	1019
Sep-05	42	133	163	319	192	242	109	34	1234
Oct-05	27	99	155	339	439	273	101	23	1456
Nov-05	17	60	90	178	112	108	37	9	610
Dec-05	11	44	52	36	6	17	7	1	174
Jan-06	6	23	25	8	2	6	3	0	73
Feb-06	0	0	0	0	0	1	0	0	2
Mar-06	26	15	16	10	7	14	6	2	97
Apr-06	83	214	203	95	29	64	45	23	756
May-06	23	62	62	53	31	59	32	17	337
Jun-06	23	12	11	19	31	52	30	36	213
Jul-06	34	12	13	37	36	63	68	117	380
Aug-06	26	28	38	123	76	131	123	33	579
Sep-06	25	59	100	297	132	192	86	30	921
Oct-06	38	133	215	524	291	384	145	38	1768
Nov-06	29	105	170	418	164	291	114	30	1322
Dec-06	1	3	3	1	1	2	1	0	12
Totals	819	1,509	1,863	3,118	1,999	2,634	1,377	624	13,943

Table 8. Population estimates for white sturgeon in the Lower Fraser River, by sampling region, as of 1 January 2006.

	Sampling Region				95% HPD[1]		
	From	**To**	**Zone Codes**	**Mean**	**Low**	**High**	**Std. Dev**
A	Georgia Strait	East Annacis Is.	S	4,090	3,090	5,190	542
B	East Annacis Is.	Mission Br.	3 to 6	14,600	13,380	15,860	630
C	Mission Br.	Hwy 1 Br. (Hope)	8 to 13	24,668	23,820	25,530	433
D	Hwy 1 Br. (Hope)	Yale	14	3,599	2,435	4,915	653
			Total	46,957	44,719	49,195	1,142

[1] HPD - Highest Probability Density . See Nelson et al. 2004 for explanation of this statistic.

Table 9. Population estimates for white sturgeon in the Lower Fraser River, by 20-cm size class, as of 1 January 2006. Estimates standardized to the mean total estimate (see Table 8).

Size		Percent	HPD[2] (% of MLE[1])		
Class (cm)	**MLE[1]**	**of MLE[1]**	**Low**	**High**	**CV[3] (%)**
40-59	1,968	4.2	1.9	12.0	47.1
60-79	8,083	17.2	14.6	20.6	8.8
80-99	10,306	21.9	20.2	24.0	4.4
100-119	8,758	18.7	17.2	20.3	4.2
120-139	6,014	12.8	11.7	14.0	4.5
140-159	4,212	9.0	8.2	9.9	4.9
160-179	3,217	6.9	6.1	7.7	5.8
180-199	1,978	4.2	3.6	4.9	7.5
200-219	1,558	3.3	2.7	4.2	11.3
220-239	548	1.2	0.8	1.7	17.6
240-259	315	0.7	0.4	1.2	27.4
Total	46,957	100.0			3.5

[1] MLE - Maximum Likelihood Estimate
[2] HPD - Highest Probability Density
[3] CV - Coefficient of Variation

Table 10. Summary of the distribution of white sturgeon recapture events, and the total number of recapture events, for tags applied to sturgeon under the FRSCS monitoring and assessment program, from 1999-2006.

Number of Recaptures	Number of Recapture Events	Total Number of Recapture Events
1	5838	5838
2	1695	3390
3	538	1614
4	153	612
5	58	290
6	15	90
7	8	56
8	1	8
Total Recapture Events (1999-2006)		**11,898**

Table 11. Summary of changes in the annual population estimates, and respective proportional (percent) changes, of white sturgeon in the lower Fraser River, 1999-2006, and respective changes since 2003.

Population Assessment Year:	1999	2001	2002	2003	2004	2005	2006
Mean (Annual) Population Estimate:	47,431	50,654	57,262	**62,611**	56,268	48,995	46,957
Change (No. Sturgeon) from previous (annual) estimate:	-	3,223	6,608	5,349	-6,343	-7,273	-2,038
Percent change from previous (annual) estimate:	-	6.8%	13.0%	9.3%	-10.1%	-12.9%	-4.2%
Change (No. Sturgeon) from 2003 estimate:	-	-	-	-	-6,343	-13,616	-15,654
Percent change from 2003 estimate:	-	-	-	-	-10.1%	-21.7%	-25.0%

FIGURES

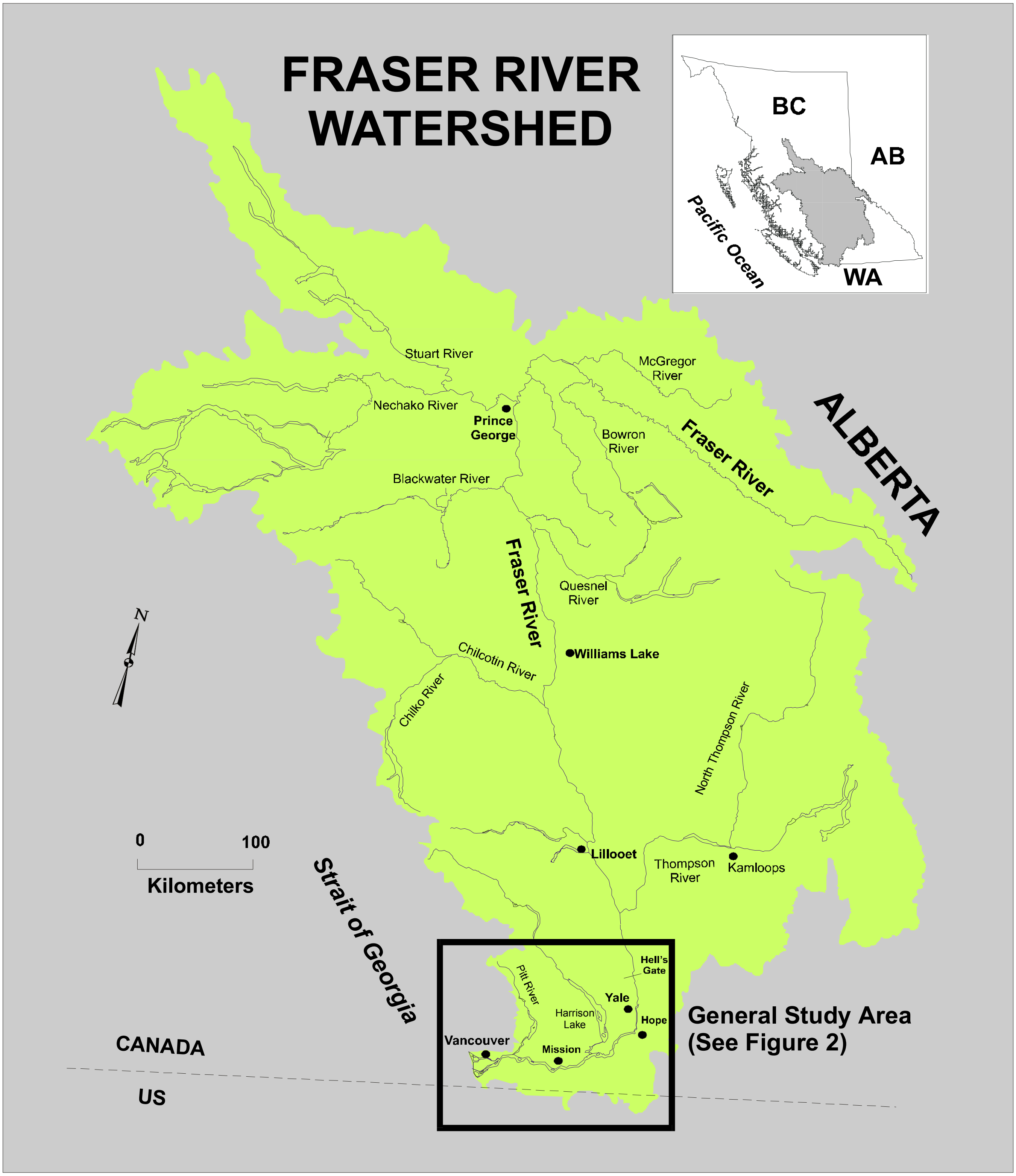


Figure 1. Map of the Fraser River watershed and its location in BC, and the general study area for the Lower Fraser River White Sturgeon Monitoring and Assessment Program 1999-2006.

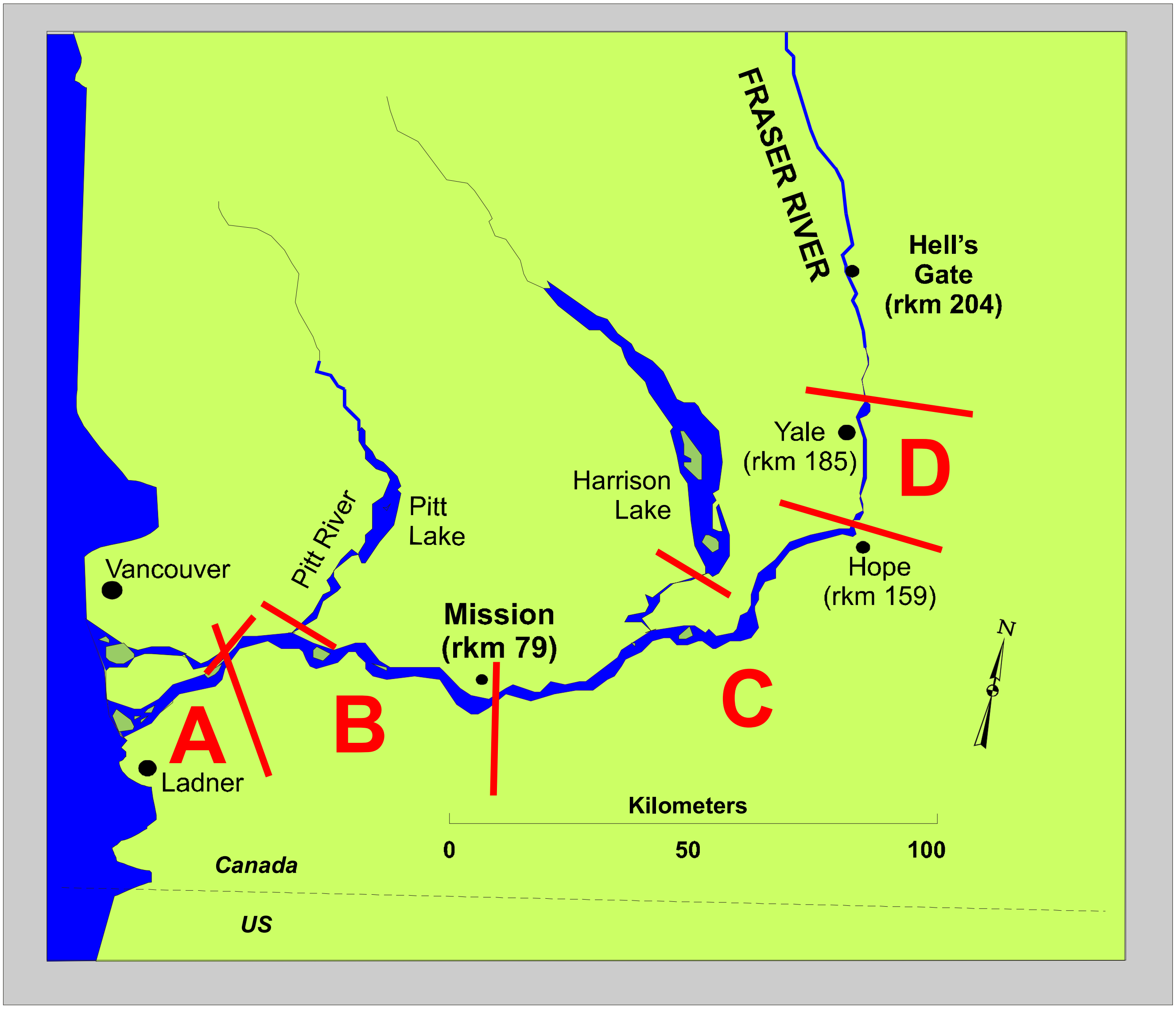


Figure 2. Illustration of the general study area and the location of the four main sampling regions (A, B, C, and D) used for data summaries presented in this report. See Table 2 for a description of the boundaries for each sampling region.

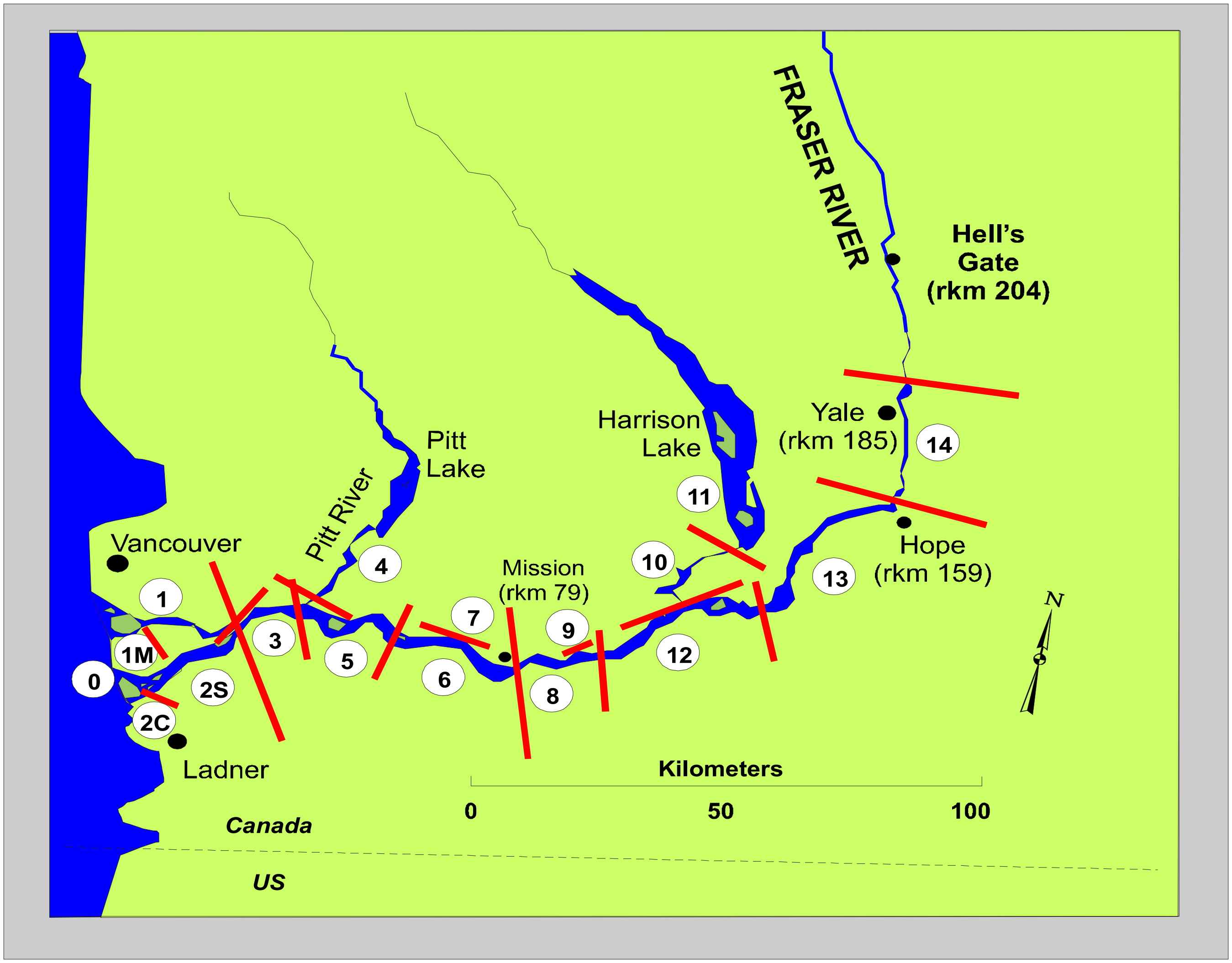


Figure 3. Locations of sampling zones used for data summaries during the Lower Fraser River White Sturgeon Monitoring and Assessment Program 1999-2006.

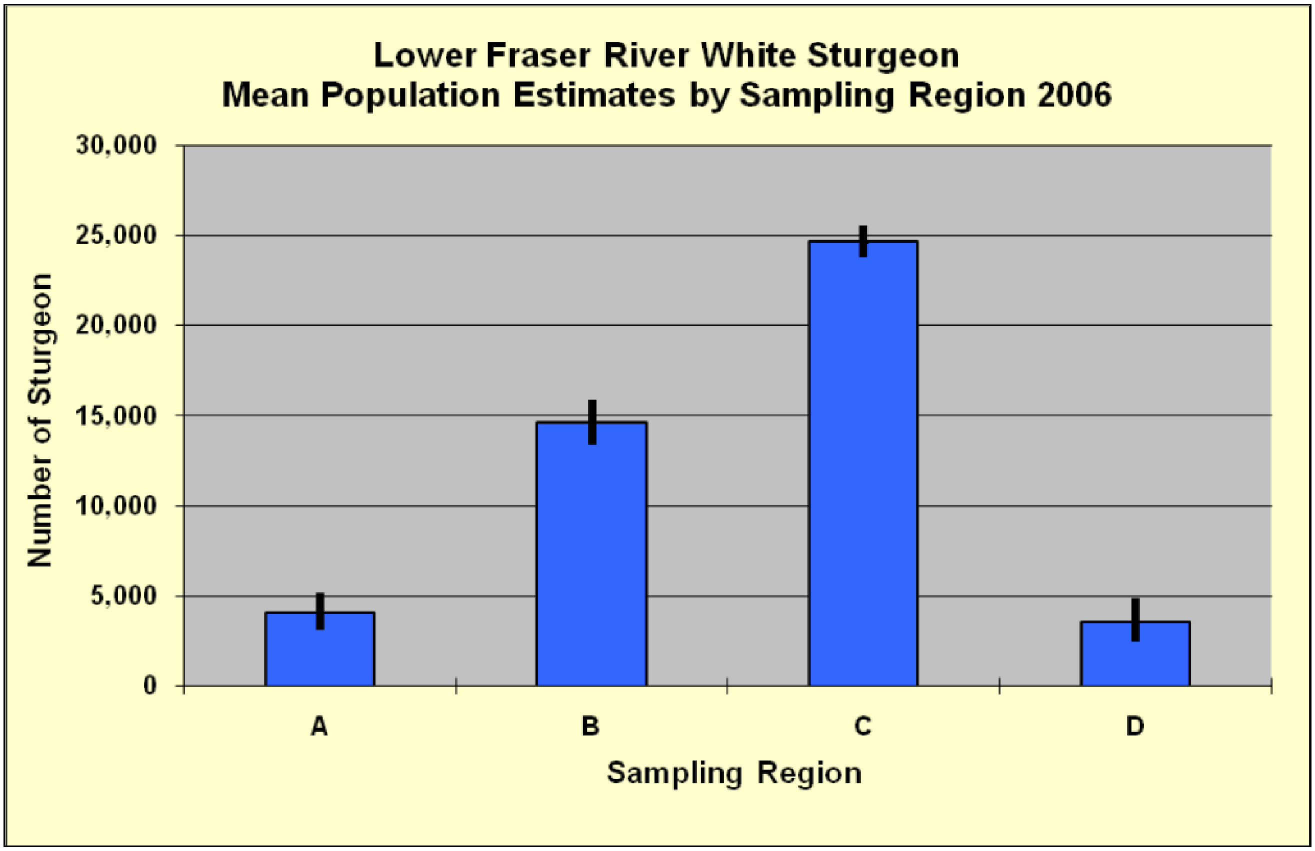


Figure 4. Mean population estimates of white sturgeon in the lower Fraser River, by sampling region, as of 1 January 2006 (see Table 8). Ranges show the 95% Highest Probability Density.

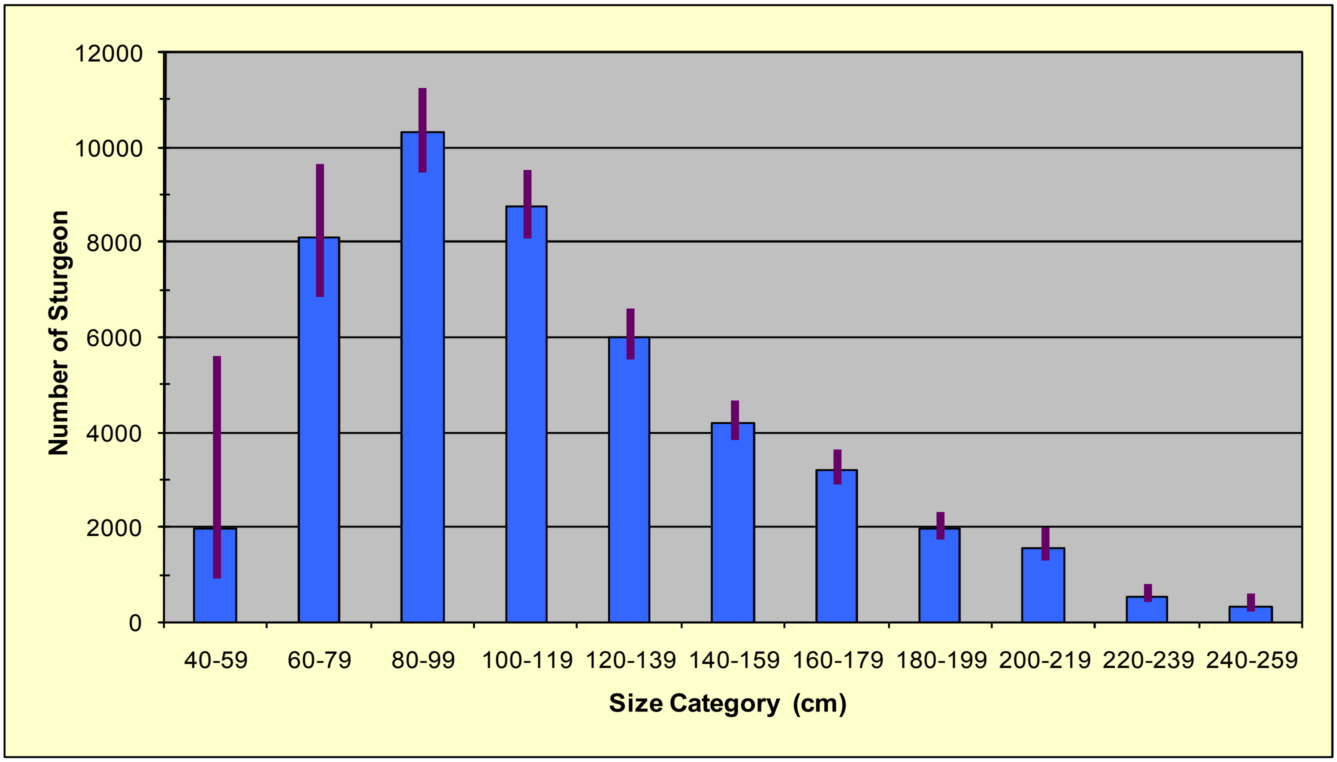
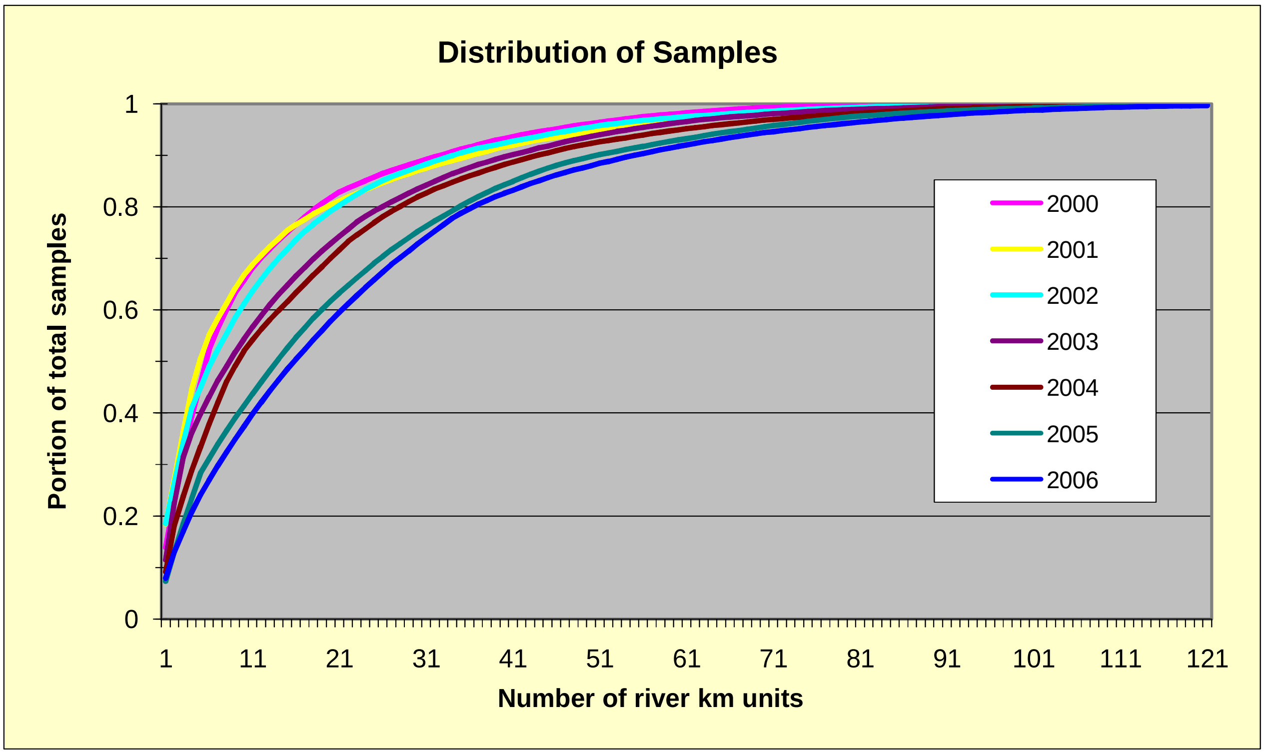


Figure 5. Mean population estimates of white sturgeon in the lower Fraser River, by 20-cm size category, as of 1 January 2006. Ranges show the 95% Highest Probability Density. All sampling regions are combined for this analysis.



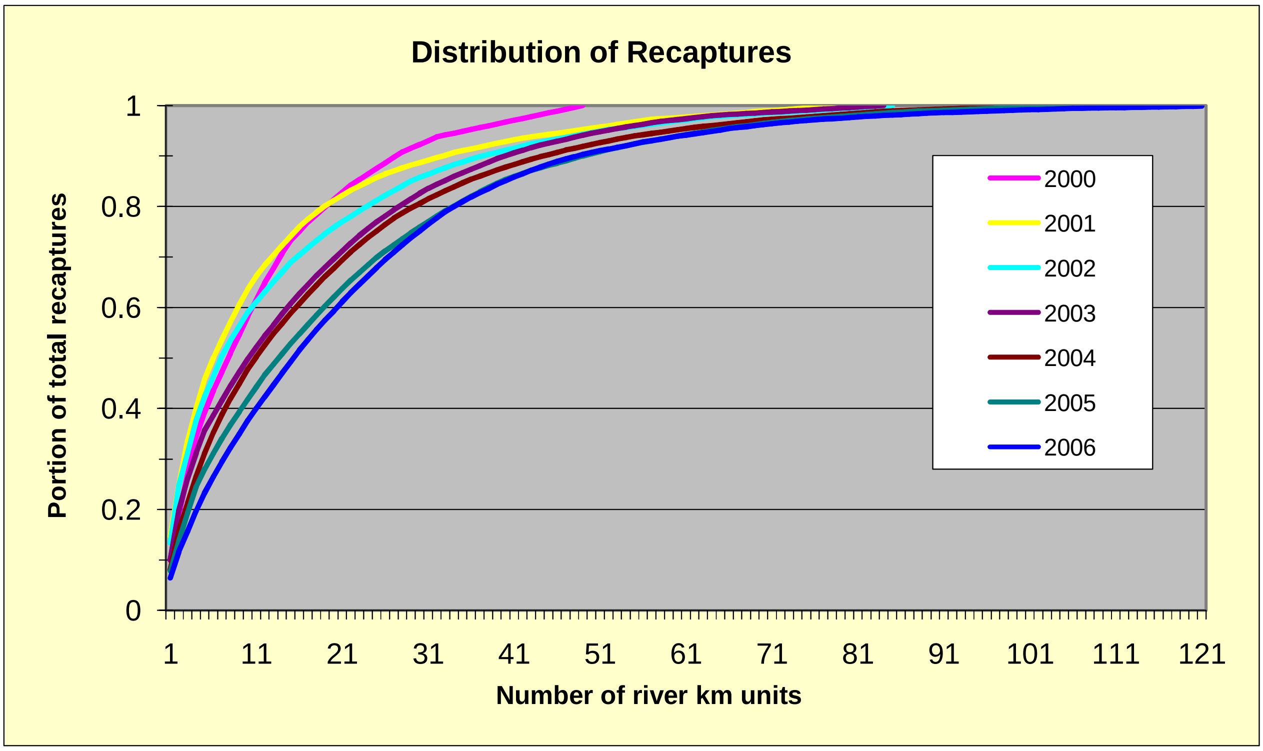


Figure 6. Illustrations of the degree to which the distribution (geographic spread within the study area, in “river km units”) of applied sampling effort, and the respective distribution of recapture events, has changed from 2000 to 2006. Curves closer to the y-axis indicate that fewer sampling locations (river km units) comprise a larger portion of the respective total sturgeon sample (top chart) or recaptured sturgeon (bottom chart) than curves farther from the y-axis.

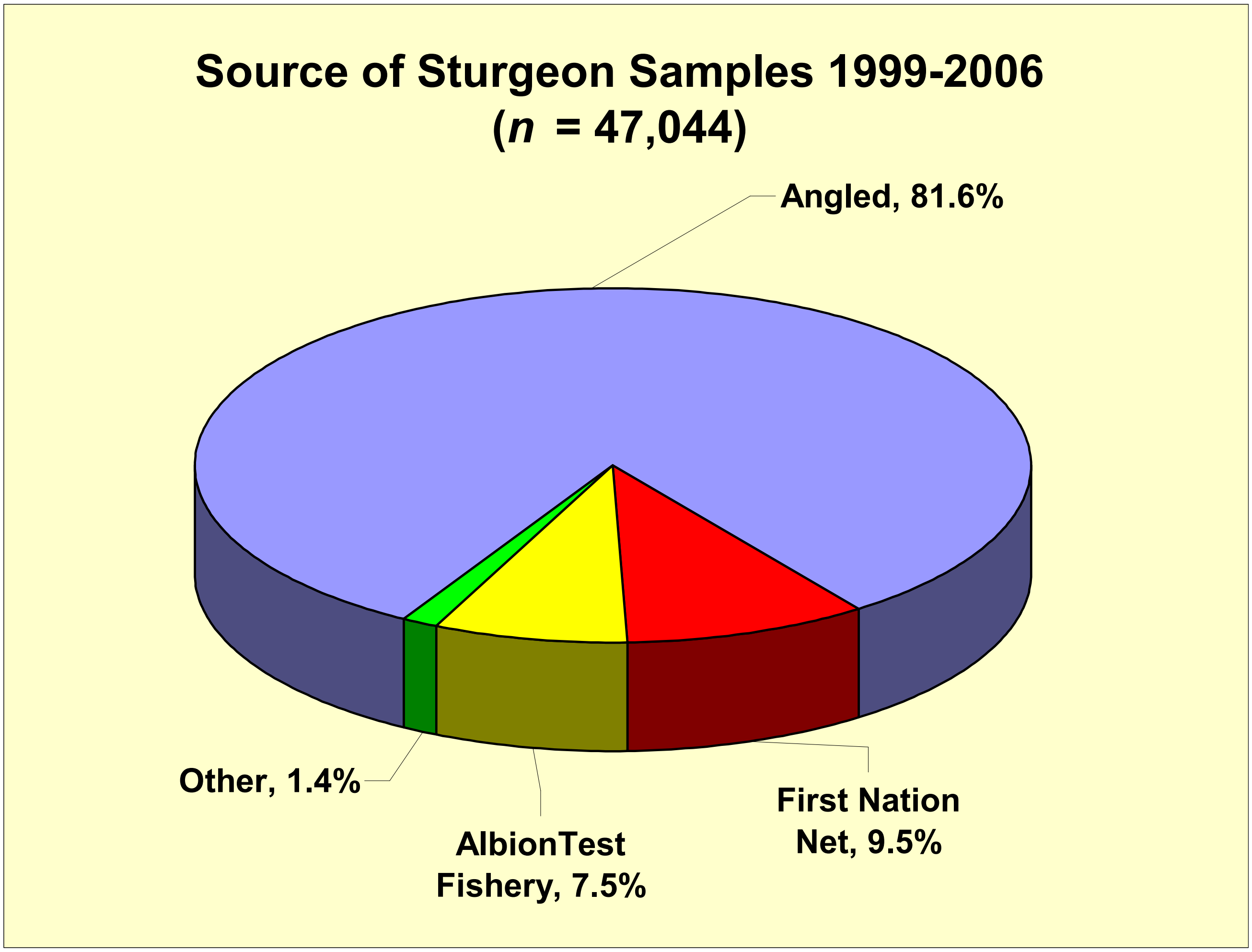
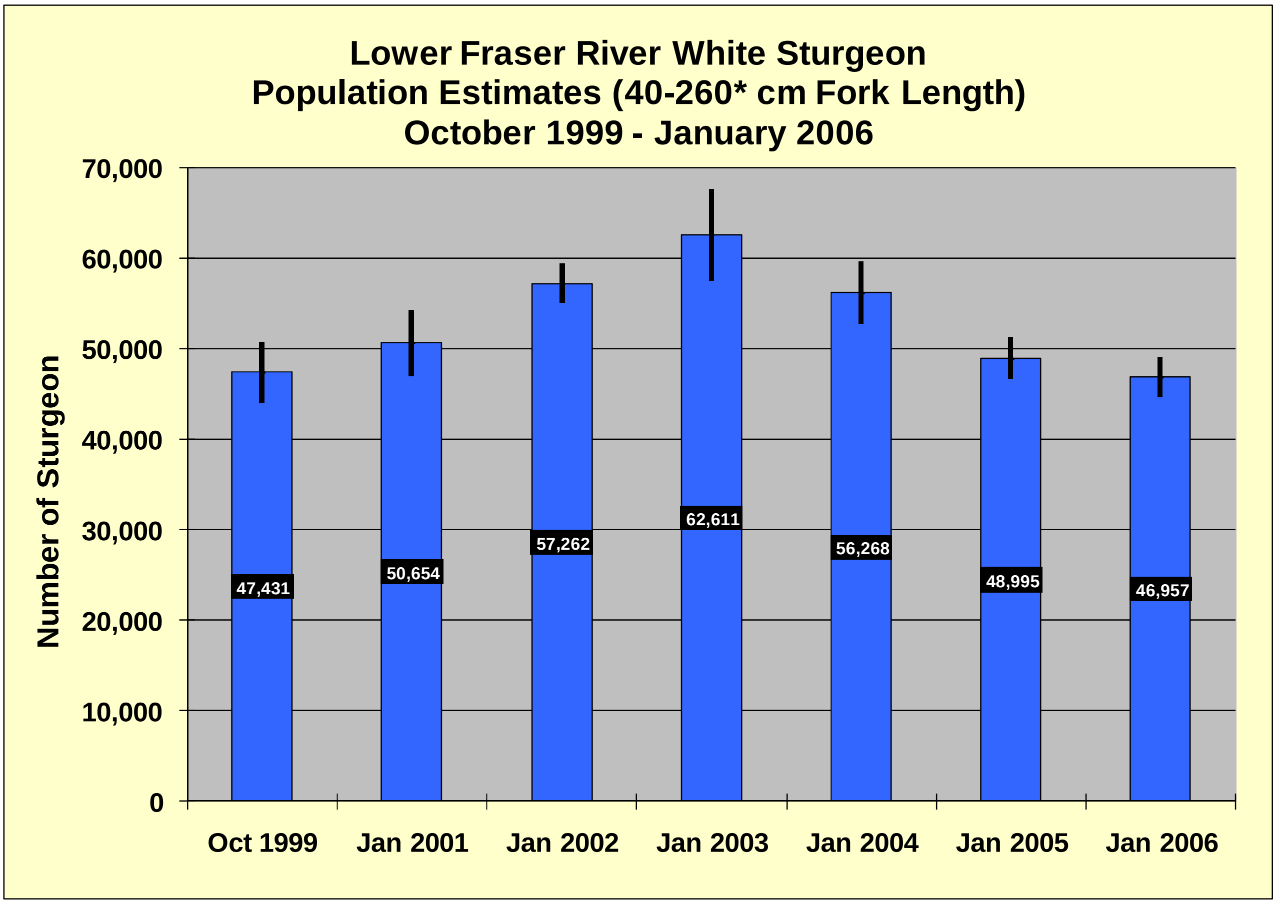


Figure 7. Sources of sturgeon samples that have contributed to the FRSCS Lower Fraser White Sturgeon Monitoring and Assessment Program from 1999-2006 (total sample of scanned sturgeon through December 2006 was 47,044).



Note: The estimates for Jan 2001 and Jan 2003 are date mid-points for population estimates (before and after January 2002; see Table 9, Nelson et al. 2004)
* The1999, 2001, 2002, and 2003 estimates do not include fish over 220 cm
* The Jan 2004 estimate is the mid-point of 2003-2004 (Jan 2004) and includes fish from 220-240 cm FL (303 fish)
* The Jan 2005 estimate is the mid-point of 2004-2005 (Jan 2005) and includes fish from 220-260 cm FL (545 fish)
* The Jan 2006 estimate is the mid-point of 2005-2006 (Jan 2006) and includes fish from 220-260 cm FL (874 fish)

Figure 8. Comparison of mean annual population estimates of lower Fraser River white sturgeon, 1999-2006. Confidence ranges show the 95% Highest Probability Density. All sampling regions are combined for this analysis.

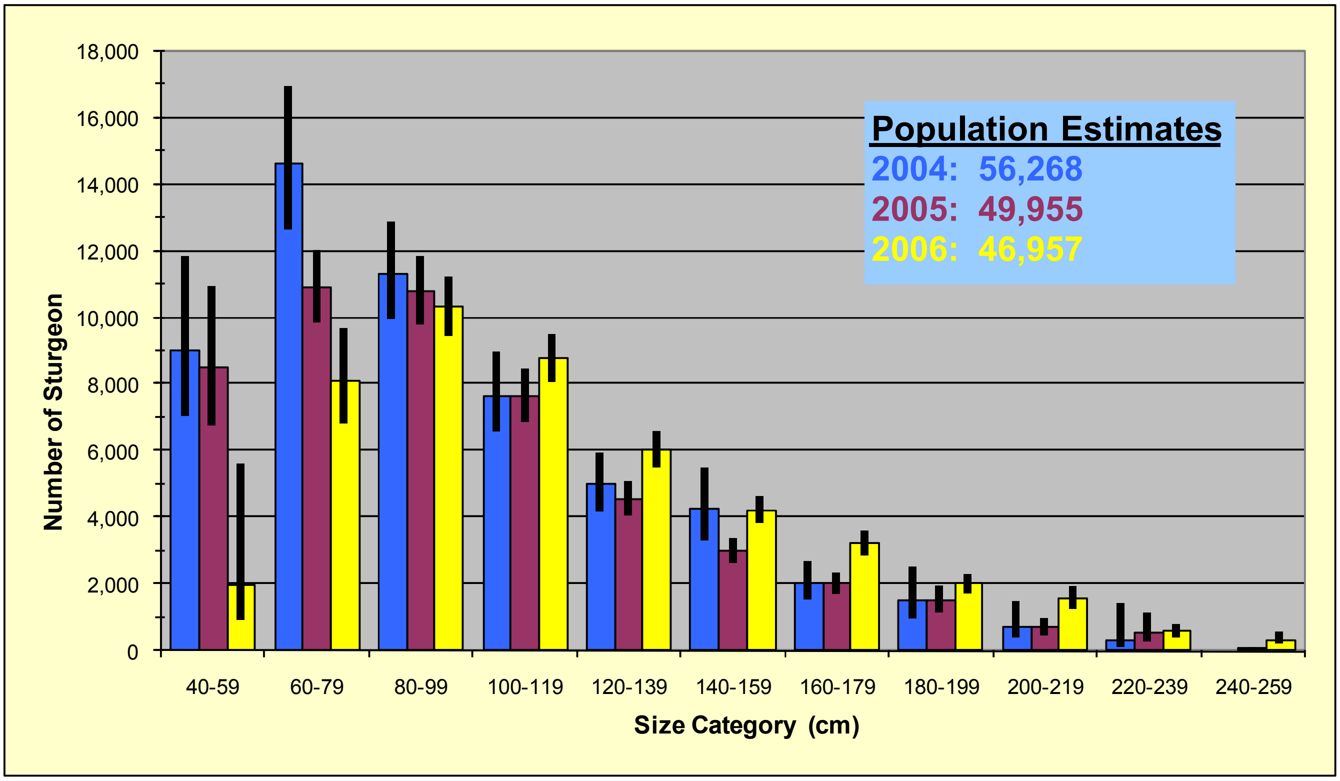


Figure 9. Comparison of mean population estimates of white sturgeon in the lower Fraser River, by 20-cm size category, for assessment years 2004, 2005, and 2006. Ranges show the 95% Highest Probability Density.

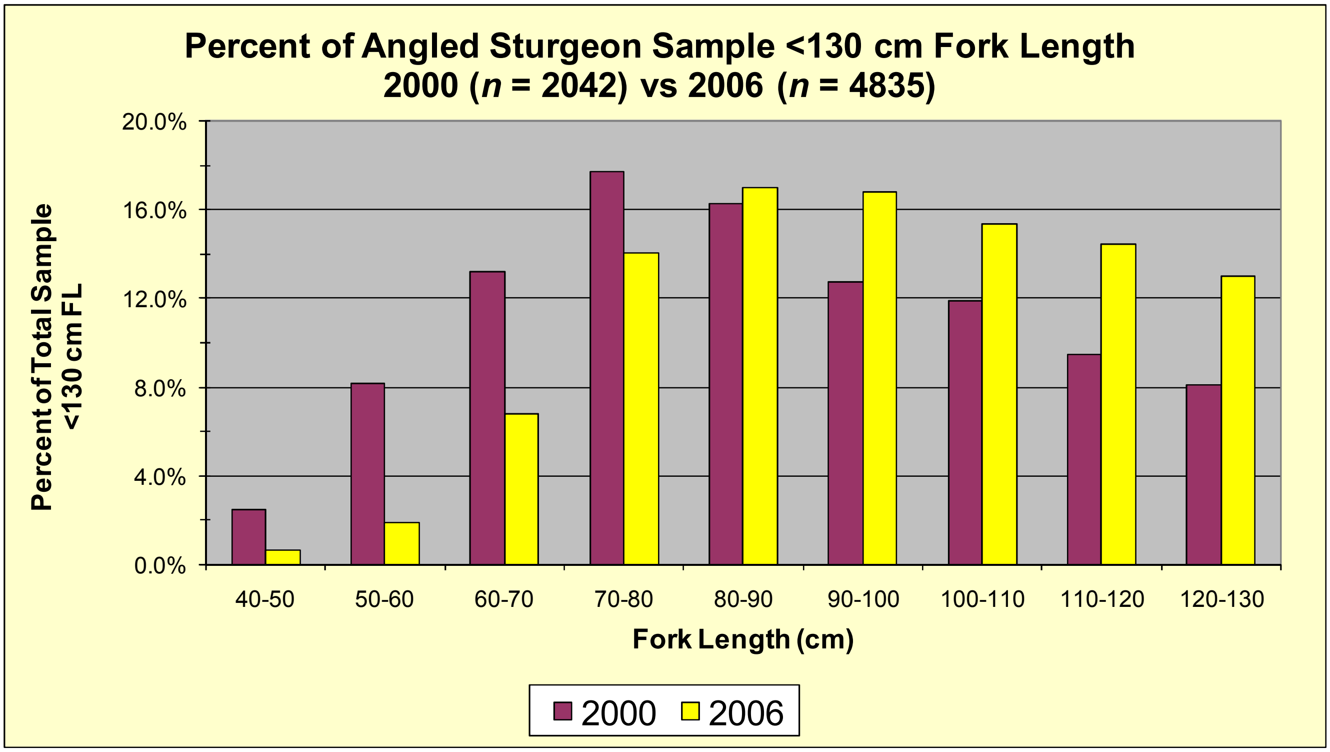


Figure 10. Illustration of the comparative percentages of sampled sturgeon less than 130 cm FL, by 10-cm size groups, captured by angling in 2000 and 2006.

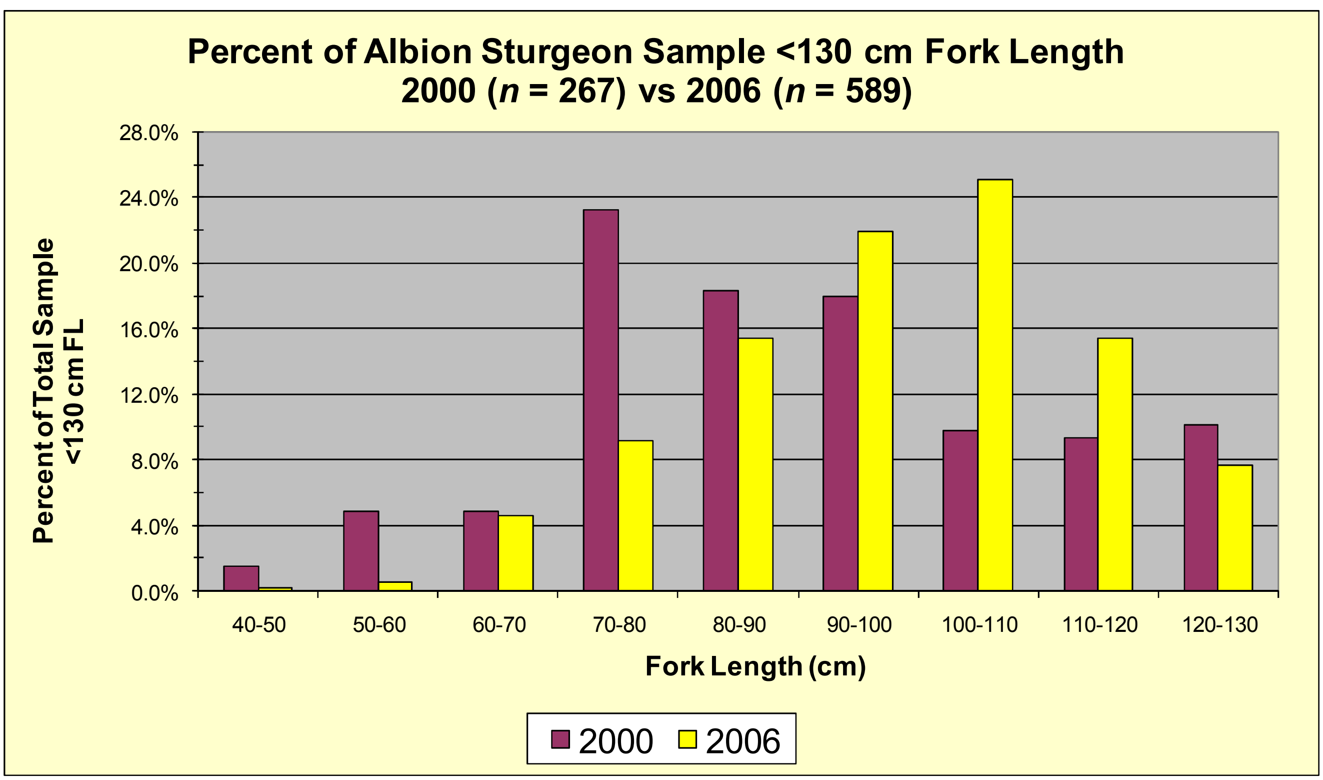


Figure 11. Illustration of the comparative percentages of sampled sturgeon less than 130 cm FL, by 10-cm size groups, captured in the Albion Test Fishery in 2000 and 2006.

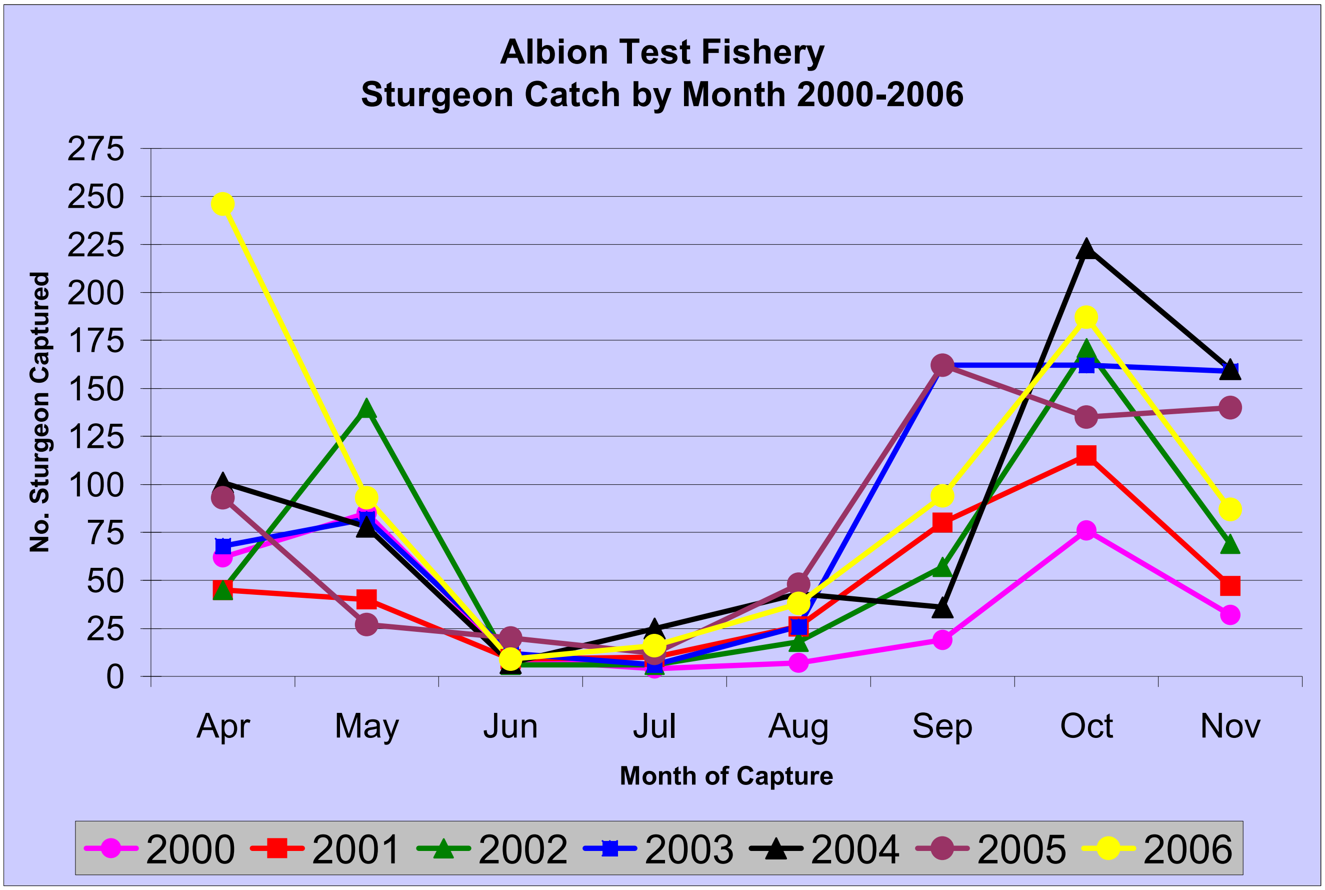


Figure 12. Comparison of the number of white sturgeon (all sizes) captured in the Albion Test Fishery, by like month, in 2000-2006. The Albion Test Fishery (a test gill net) applies relatively similar levels of effort (two 20-min sets during high slack tide) on a daily basis from April-November at the same location (sampling region B, rkm 58) in the mainstem Fraser River.

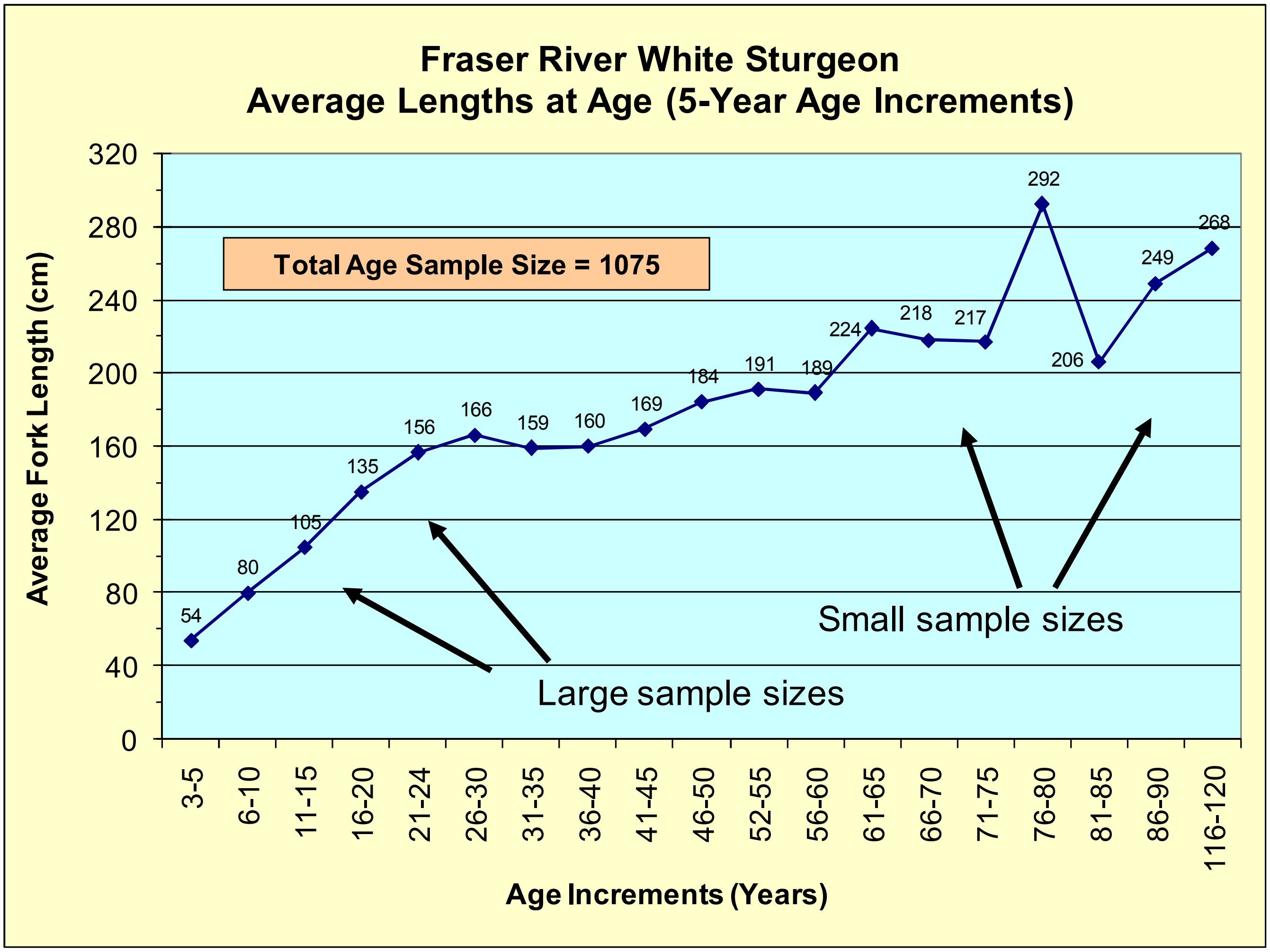


Figure 13. Average lengths at estimated age for Fraser River white sturgeon sampled from 1995-99 (data provided by Ted Down, BC Fisheries). Age data were derived from pectoral fin ray analysis and include samples from throughout the Fraser River watershed.

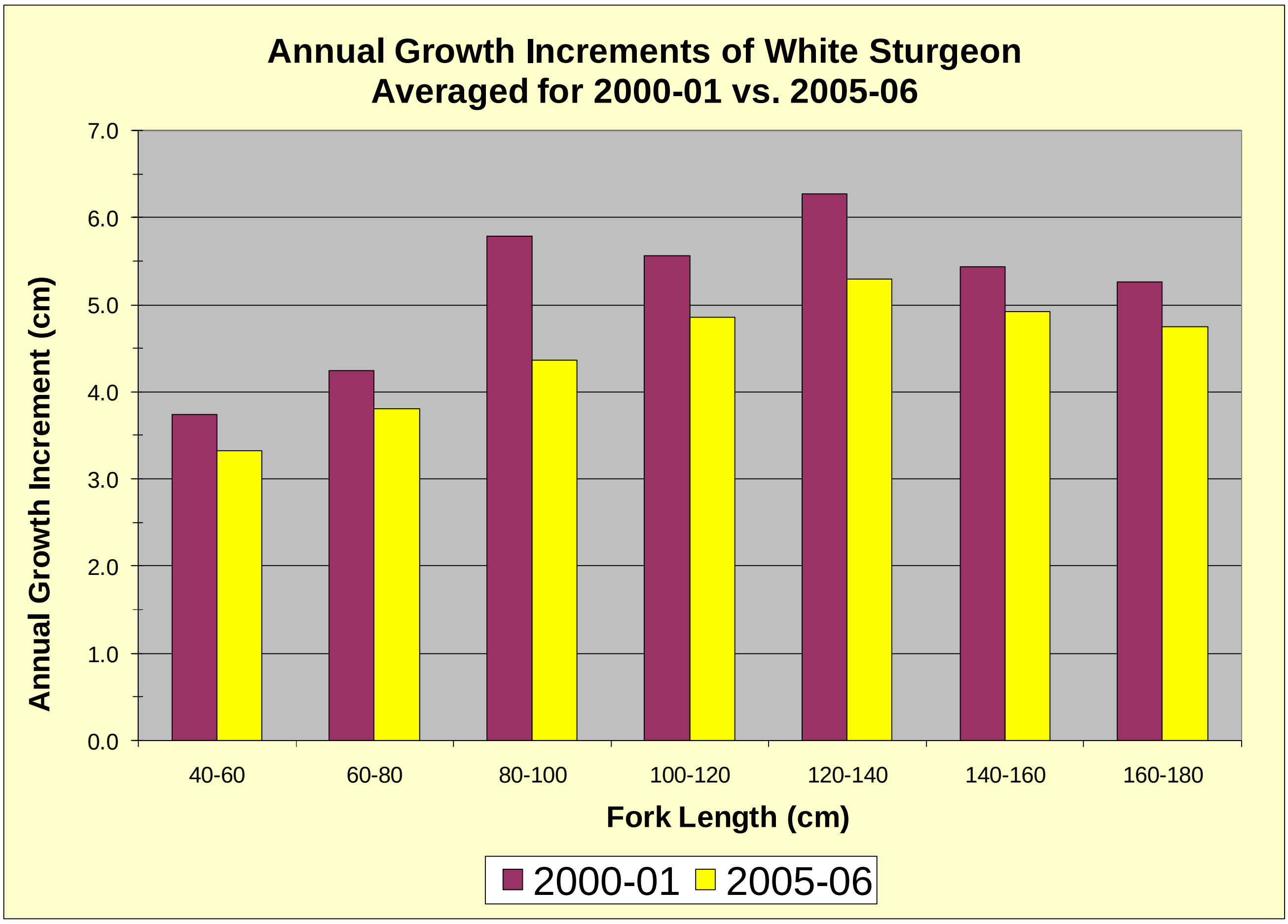


Figure 14. Comparison of average annual growth increments of white sturgeon (cm), by 20-cm size groups, for the periods 2000-2001 (n = 477) and 2005-2006 (n = 4509). Growth was determined from measurements obtained from individual, tagged sturgeon that were subsequently recaptured.

APPENDIX A

Sturgeon biosampling, tagging, and recapture data entry form

FRASER RIVER STUGEON CONSERVATION SOCIETY FAX to Jim Rissling: 604-792-2630 (phone: 604-792-4368)

WHITE STURGEON BIOSAMPLING, TAGGING, AND MARK- RECAPTURE RECORDS Page:______ of ________

Name/Phone Number of Person that Recorded Data: ____________________

Phone No: ____________________

Date (dd/mmm/yy ____________ Sampling Area: ____________ Weather: ____________ No. Passengers: ____________

Vessel Information: Vessel Name ____________ Launch Location ____________ Launch Time: ____________ Return Time: ____________

Angling/Sampling Effort		Start Time	End Time	Total Minutes	Start Time	End Time	Total Minutes	Start Time	End Time	Total Minutes	Grand Total (Minutes)
Rod/Gear 1 (Name)											
Rod/Gear 2 (Name)											
Rod/Gear 3 (Name)											
Rod/Gear 4 (Name)											

COMPLETE FOR ALL STURGEON CAPTURED						TAGS APPLIED	RECAPTURES	tn2OTHER	
Fish No.	**River Km (Captured)**	**Was the Sturgeon Scanned? (Yes/No)**	**Fork Length (cm)**	**Girth (cm)**	**Deformity / Wound Code[1]**	**Verified (Scanned at release) Tag Number**	**Tag Number**	**Condition code for sturgeon at release[2]**	**Comments**

Comments:

[1]Deformity/wound/scar codes: DEF = physical deformity; BLED = bleeding; BITE = seal bite; CUT = slice or tear; NET = net scar; OTHER = other (note in comments)

[2]Condition codes: 1 = vigorous, no bleeding; 2 = vigorous, bleeding; 3 = lethargic, no bleeding; 4 = lethargic, bleeding; 5 = dead

APPENDIX B

Lower Fraser River sturgeon sampling, tagging, and recapture summary, by month and year, 1999-2006.

Appendix B. Lower Fraser River sturgeon sampling, tagging, and recapture summary, by month and year, 1999-2006.

Month	No. Scanned (All)	Released **With** Tag (Head)	No. Scanned, **Not** Tagged, **Not** Recaptured	No. Recaptured (Head Tag)	Mark Rate (%)	Year	No. Scanned (All)	No. Released **With** Tag (Head)	No. Scanned, **Not** Tagged, **Not** Recaptured	No. Recaptured (Head Tag)	Mark Rate (%)
Oct-99	70	64	6	0	0.0%						
Nov-99	201	177	24	0	0.0%						
Dec-99	157	143	14	0	0.0%	**1999**	428	384	44	0	**0.0%**
Jan-00	38	37	1	0	0.0%						
Feb-00	148	135	6	7	4.7%						
Mar-00	232	191	33	8	3.4%						
Apr-00	286	265	12	9	3.1%						
May-00	380	351	17	12	3.2%						
Jun-00	279	257	15	7	2.5%						
Jul-00	752	695	27	30	4.0%						
Aug-00	471	424	23	24	5.1%						
Sep-00	469	437	5	27	5.8%						
Oct-00	696	617	37	42	6.0%						
Nov-00	561	506	12	43	7.7%						
Dec-00	57	45	6	6	10.5%	**2000**	4369	3960	194	215	**4.9%**
Jan-01	178	165	0	13	7.3%						
Feb-01	152	134	0	18	11.8%						
Mar-01	299	250	0	49	16.4%						
Apr-01	423	340	30	53	12.5%						
May-01	410	361	5	44	10.7%						
Jun-01	509	427	8	74	14.5%						
Jul-01	434	357	14	63	14.5%						
Aug-01	844	717	20	107	12.7%						
Sep-01	582	484	4	94	16.2%						
Oct-01	851	711	26	114	13.4%						
Nov-01	512	417	6	89	17.4%						
Dec-01	316	197	78	41	13.0%	**2001**	5510	4560	191	759	**13.8%**
Jan-02	117	60	46	11	9.4%						
Feb-02	147	45	83	19	12.9%						
Mar-02	138	65	53	20	14.5%						
Apr-02	251	107	102	42	16.7%						
May-02	343	173	114	56	16.3%						
Jun-02	225	131	36	58	25.8%						
Jul-02	730	529	87	114	15.6%						
Aug-02	866	622	78	166	19.2%						
Sep-02	396	149	151	96	24.2%						
Oct-02	1149	582	368	199	17.3%						
Nov-02	531	187	232	112	21.1%						
Dec-02	157	97	31	29	18.5%	**2002**	5050	2747	1381	922	**18.3%**
Jan-03	72	55	11	6	8.3%						
Feb-03	39	20	12	7	17.9%						
Mar-03	131	89	28	14	10.7%						
Apr-03	451	290	77	84	18.6%						
May-03	553	383	84	86	15.6%						
Jun-03	310	180	73	57	18.4%						
Jul-03	474	311	92	71	15.0%						
Aug-03	674	473	89	112	16.6%						
Sep-03	1132	759	134	239	21.1%						
Oct-03	835	586	68	181	21.7%						
Nov-03	659	395	132	132	20.0%						
Dec-03	114	97	1	16	14.0%	**2003**	5444	3638	801	1005	**18.5%**
Jan-04	144	122	0	22	15.3%						
Feb-04	316	272	3	41	13.0%						
Mar-04	145	114	3	28	19.3%						
Apr-04	743	575	7	161	21.7%						
May-04	589	447	4	138	23.4%						
Jun-04	430	314	7	109	25.3%						
Jul-04	493	362	5	126	25.6%						
Aug-04	656	434	44	178	27.1%						
Sep-04	827	574	14	239	28.9%						
Oct-04	1683	908	310	465	27.6%						
Nov-04	1092	603	205	284	26.0%						
Dec-04	97	64	6	27	27.8%	**2004**	7215	4789	608	1818	**25.2%**
Jan-05	28	23	0	6	21.4%						
Feb-05	221	178	0	43	19.5%						
Mar-05	288	222	1	65	22.6%						
Apr-05	831	572	20	239	28.8%						
May-05	475	282	28	165	34.7%						
Jun-05	739	440	16	283	38.3%						
Jul-05	738	480	20	238	32.2%						
Aug-05	1424	788	155	481	33.8%						
Sep-05	1835	768	415	652	35.5%						
Oct-05	2092	966	319	807	38.6%						
Nov-05	1076	420	321	335	31.1%						
Dec-05	286	137	91	58	20.3%	**2005**	10033	5276	1386	3372	**33.6%**
Jan-06	83	68	0	15	18.1%						
Feb-06	2	2	0	0	0.0%						
Mar-06	116	76	3	37	31.9%						
Apr-06	885	582	8	295	33.3%						
May-06	437	253	10	174	39.8%						
Jun-06	274	161	6	107	39.1%						
Jul-06	510	289	13	208	40.8%						
Aug-06	798	444	32	322	40.4%						
Sep-06	1305	682	9	614	47.0%						
Oct-06	2555	1331	13	1211	47.4%						
Nov-06	1863	1054	38	770	41.3%						
Dec-06	167	113	0	54	32.3%	**2006**	8995	5055	132	3807	**42.3%**
Totals	**47,044**	**30,409**	**4,737**	**11,898**	**25.3%**	**1999-2006**	**47,044**	**30,409**	**4,737**	**11,898**	**25.3%**